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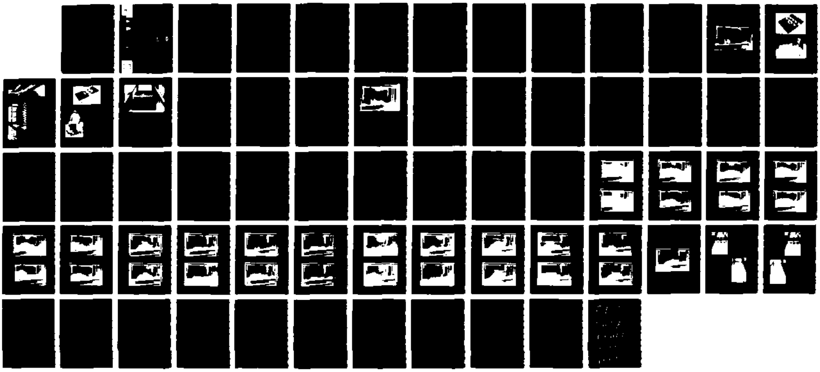

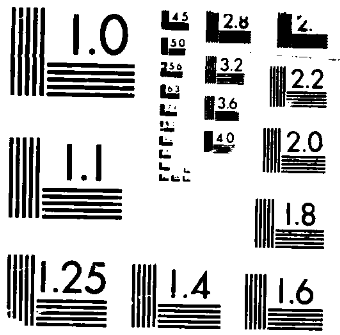

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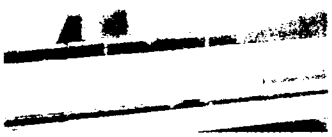

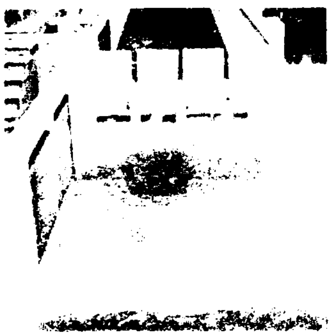

OLD RIVER LOW-SILL CONTROL STRUCTURE: DYNAMIC HYDRAULIC FORCES ACTING ON THE STILLING BASIN, SURVEY BOAT SAFETY, AND DEBRIS PASSAGE

Hydraulic Model Investigation

by

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US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

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			Debris passage	Module
			Gate bays	Survey boat

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Tests were conducted in 1:36-scale section models of the high and low bays to develop guidance for rehabilitation of the existing stilling basin, to develop guidance for the safety of survey boats operating in the approach to the structure, and to evaluate characteristics of debris passage through the structure. The portion of the basin between the baffles and end sill was protected with sloping modules constructed of steel and grout, and tests were conducted to determine the hydraulic forces acting on the modules. A flow spoiler design to reduce uplift forces on the modules and not increase the sliding and uplift forces acting on the stilling basin was also investigated.

Survey boat safety tests indicated that a typical survey boat operating upstream of the gate bays should be safe with gate openings equal to or less than 30 percent of the head on the crest.

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19. ABSTRACT (Continued).

Debris passage tests indicated that debris up to 35 ft long and 3.0 ft thick would pass through the structure with gate openings equal to or greater than about 30 to 40 percent of the head on the crest.

PREFACE

The model investigation was authorized by the Office, Chief of Engineers, US Army, at the request of the US Army Engineer District, New Orleans.

The study was conducted during the period December 1977 to July 1978 in the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) under the direction of Mr. H. B. Simmons, former Chief of the Hydraulics Laboratory, and under the general supervision of Messrs. J. L. Grace, Jr., former Chief of the Hydraulic Structures Division (HSD), and N. R. Oswalt, Chief of the Spillways and Channels Branch. Mr. F. A. Herrmann, Jr., is the present Chief of the Hydraulics Laboratory. Project engineer for the model study was Mr. B. P. Fletcher, assisted by Messrs. P. Bhramayana and B. Perkins, all of HSD. The model was constructed by Messrs. Selwyn W. Guy and Homer C. Greer, Instrumentation Services Division, WES, and Edmund E. McMaster, Engineering and Construction Services Division. This report was prepared by Mr. Fletcher.

Commander and Director of WES during the preparation and publication of this report was COL Dwayne G. Lee, CE. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet per second per foot	0.929	cubic metres per second per metre
degrees (angle)	0.01745329	radians
feet	0.3048	metres
kips (force)	4.448222	kilonewtons
kips (force) per foot	14.59	kilonewtons per metre
miles (US statute)	1.609347	kilometres

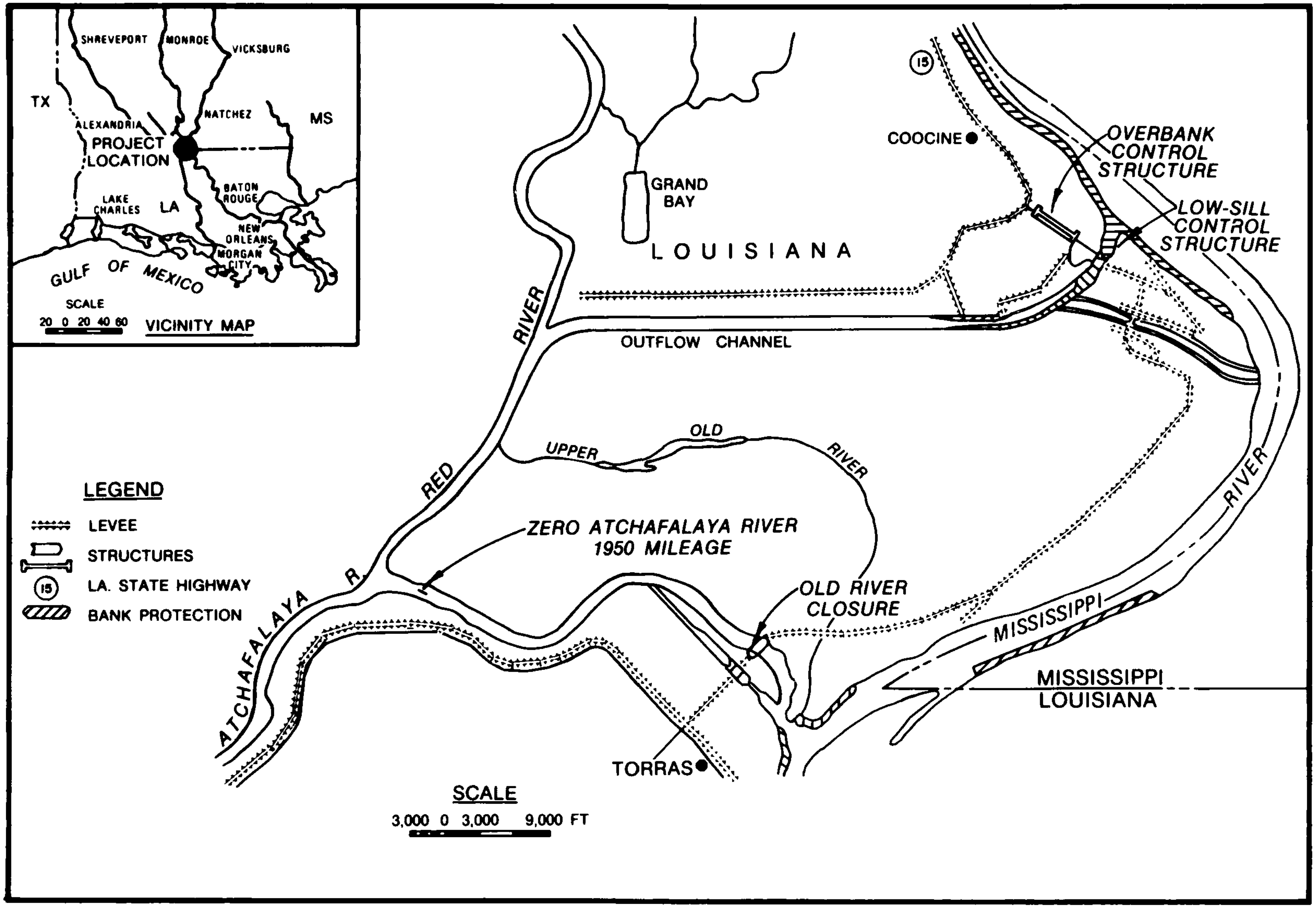

Figure 1. Vicinity map

OLD RIVER LOW-SILL CONTROL STRUCTURE: DYNAMIC HYDRAULIC FORCES ACTING ON THE STILLING BASIN, SURVEY BOAT SAFETY, AND DEBRIS PASSAGE

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Old River Low-Sill Control Structure (Figure 1) is located on the west bank of the Mississippi River approximately 50 miles* northwest of Baton Rouge, Louisiana, and approximately 35 miles southwest of Natchez, Mississippi. The low-sill control structure consists of a reinforced concrete spillway with vertical-lift gates and stilling basin, an inflow channel from the Mississippi River, and an outflow channel to the Atchafalaya River and Basin.

2. The structure has a spillway length of 566 ft between abutments and consists of eleven 44-ft-wide gate bays, Nos. 1-11 from right to left looking downstream, separated by piers. The three center bays (low gate bays) have a crest elevation of -5.0;** and the eight outer bays (high gate bays), four bays on each side of the center section, have a crest elevation of +10.0 (Plates 1 and 2). The gate bays are fitted with multileaf, vertical-lift gates operated by an overhead gantry crane.

3. The stilling basin consists of three divided sections, each with a horizontal apron that is surmounted with two rows of staggered 10-ft-high baffle piers spaced 12 ft apart and terminated with a 3-ft-high vertical end sill. The center section, located downstream of the low gate bays, is 150 ft wide and has an apron elevation of -12.0. The two outer sections, downstream of the high gate bays, are 221 ft wide and have an apron elevation of -5.0. Rehabilitation of the stilling basin apron downstream from the high and low bays was essential to repair the eroded concrete on the apron between the

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* A table of factors for converting US customary units of measurement to metric (SI) units is presented on page 3.

** All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

baffles and end sill. Rehabilitation will be provided by overlaying the portion of the apron between the baffles and end sill with modules constructed of steel with grout pumped underneath.

Purpose of Model Study

4. The primary purpose of the model study was to develop guidance for rehabilitation of the existing stilling basin. This was accomplished by conducting model tests to determine the hydrodynamic forces acting on proposed modules located immediately upstream from the end sill, the spoiler design that minimizes the uplift forces acting on the modules, and the sliding and uplift hydraulic forces, with and without the spoilers, acting on the stilling basin. Tests were also conducted to develop guidance relative to the safety of survey boats operating in the approach to the structure during control flows and to determine the temporary gate openings necessary to pass drift under the gates.

PART II: MODELS

Description

5. Two section models were constructed to a scale of 1:36; each model contained an instrumented section designed to permit the measurement of the magnitude and frequency of hydraulic forces for various flow conditions. The instrumented sections were constructed of machined aluminum, and adequate clearance between the instrumented section and adjacent portions of the model was provided to eliminate excessive friction and damping. Tests were conducted with and without the models submerged to ensure that the frequency or damping of the systems would not influence measurement of the dynamic forces.

Uplift forces acting on the modules

6. A section model used to investigate the hydrodynamic forces acting on the modules downstream from the low bays consisted of one bay, two piers, and 30 percent of each adjacent bay (Figure 2). The model simulated about a 900-ft length of the approach, 800-ft length of the exit channel, and a channel width of 88 ft. Provisions were made for installation of flow spoilers to study their effects on uplift forces on the module. Construction photographs of the instrumented section are shown in Figure 3.

7. The high bay portion of the structure was simulated to investigate forces on the module located downstream from the high bays.

Sliding and uplift forces acting on the stilling basin

8. A section model to investigate the sliding and uplift forces acting on the stilling basin downstream from the low bay portion of the structure reproduced a width of 173 ft. The model included approximately 1,100 ft of the approach, three 44-ft-wide gate bays, three gate piers, 38.8 percent of one high bay, and about 2,000 ft of exit channel. The section model including the machined aluminum instrumented section is shown in Figure 4. Figure 5 shows the instrumented portion of the section model prior to insertion in the model.

9. The 173-ft-wide section model also was used to investigate the forces acting on the stilling basin in the high bay portion (Figure 6) of the structure and to investigate debris passage and survey boat safety.

Appurtenances

10. Water used in the operation of the models was supplied by pumps,

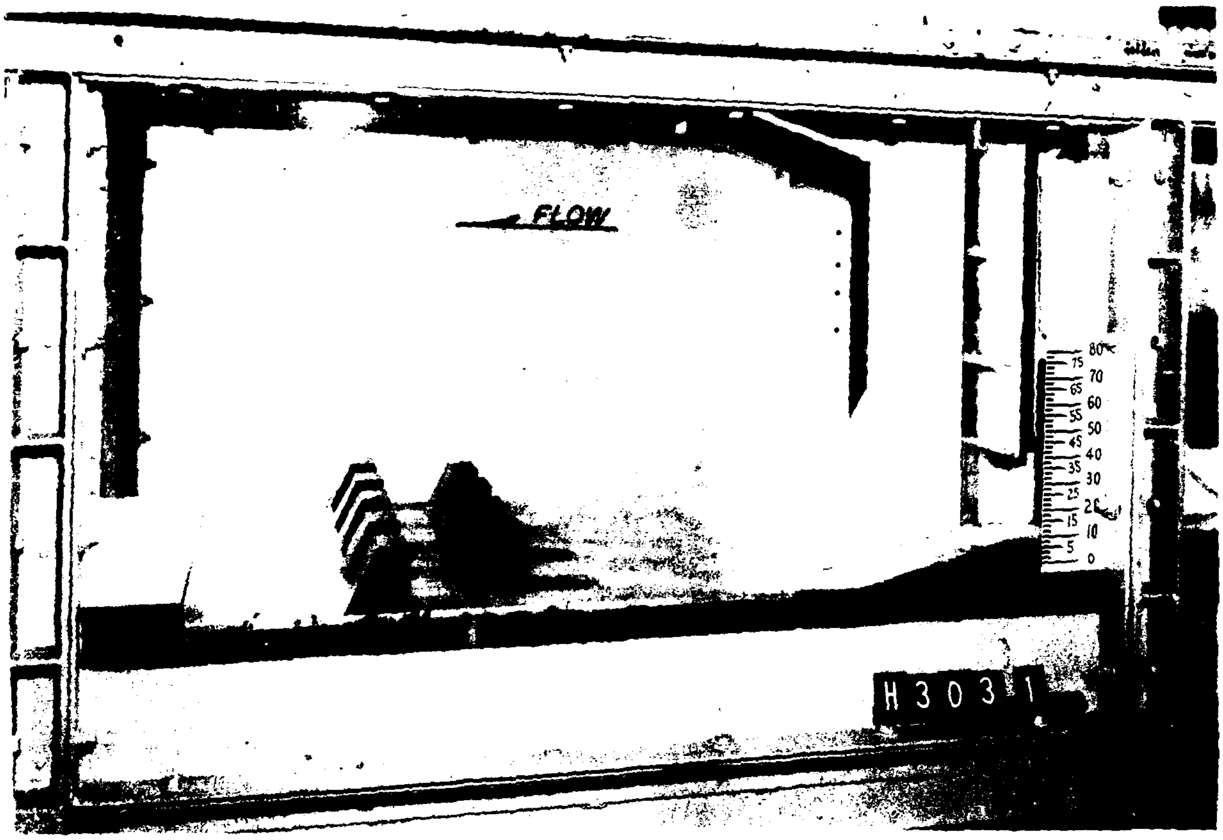
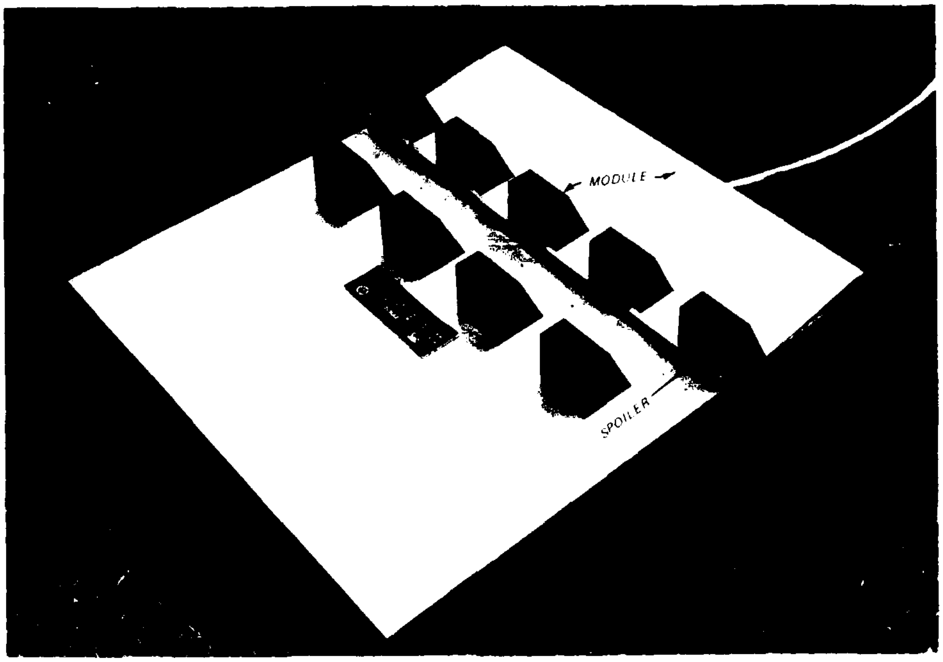


Figure 2. Side view of low bays



a. Spoiler and module

b. Underside of instrumented section

Figure 3. Instrumented section for measuring forces acting on the module

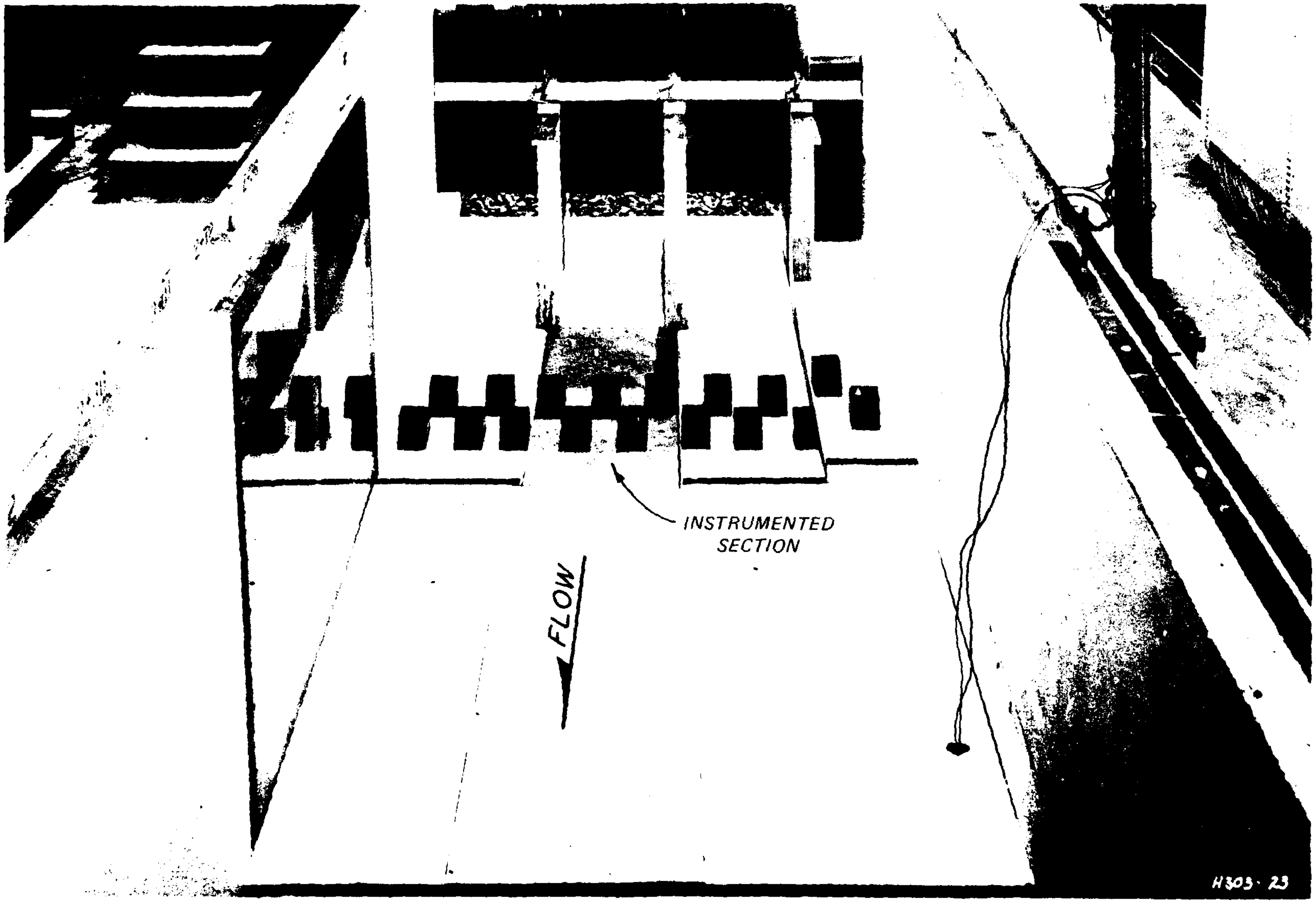
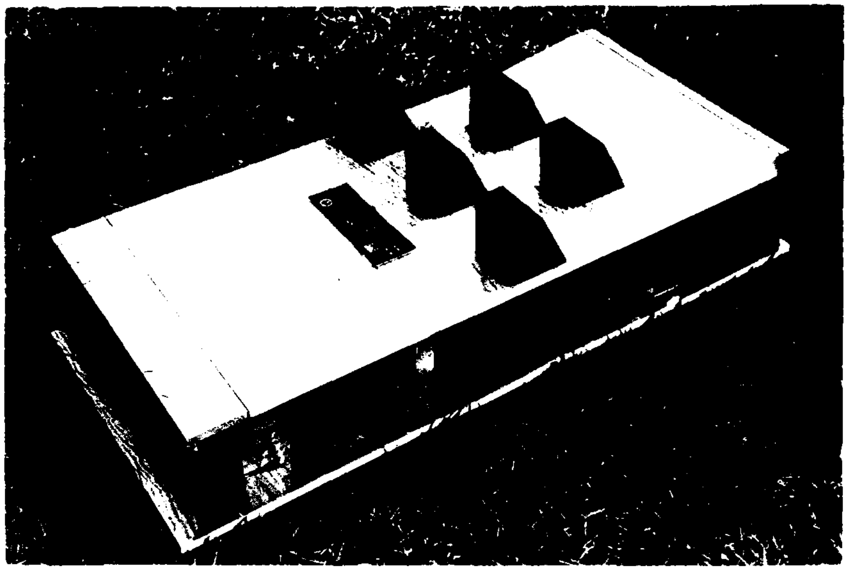


Figure 4. Upstream view of low bays



a. Assembled instrumented section

b. Top plate disconnected

Figure 5. Instrumented section for measuring sliding and uplift forces

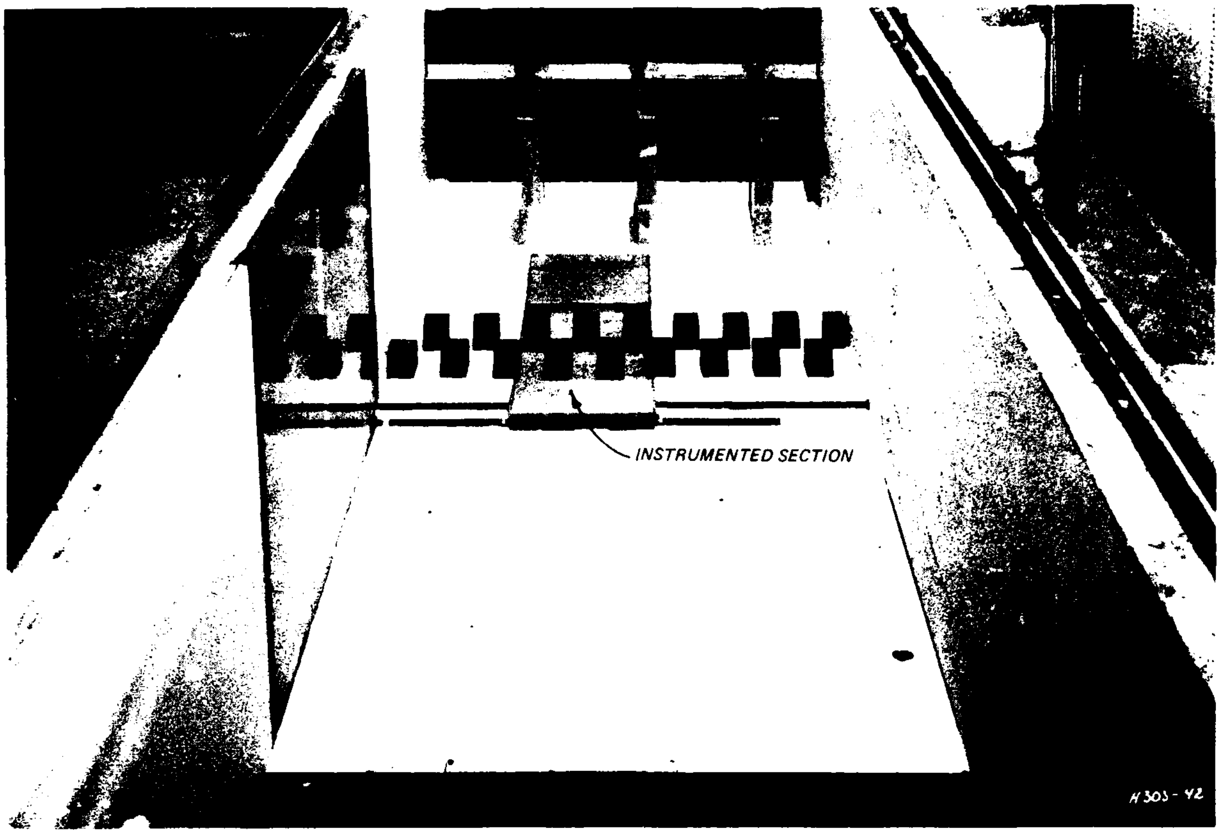


Figure 6. Upstream view of high bays

and discharges were measured by venturi meters. Steel rails set to grade along the sides of the flumes provided reference planes for measuring devices. Water-surface elevations were measured by means of point gages.

11. A transparent window was installed in the side of each model to permit visual observations and photographs of various flow conditions.

Interpretation of Model Results

12. The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and the prototype. The general relations expressed in terms of the model's scale or length ratio L_r are expressed in the tabulation below:

Dimension	Ratio	Scale Relation
Length	L_r	1:36
Area	$A_r = L_r^2$	1:296
Velocity	$V_r = L_r^{1/2}$	1:6
Discharge	$Q_r = L_r^{5/2}$	1:7,776
Time	$T_r = L_r^{1/2}$	1:6
Force	$F_r = L_r^3$	1:46,660
Frequency	$f_r = 1/L_r^{1/2}$	1:0.167

13. Measurement of each of the dimensions or variables can be transferred quantitatively from model to prototype equivalents by means of the above scale relations.

PART III: TEST AND RESULTS

Presentation of Data

14. The magnitudes of the forces presented within this report represent only the dynamic hydraulic loads acting on the structures and are not influenced by a preload or submerged weight of the structure.

Uplift Forces Acting on the Modules

Low bays

15. Tests were conducted with the low bays simulated to investigate the dynamic forces acting vertically per foot of width on the upstream portion of the modules with and without various flow spoilers located at the upstream and downstream end of the second row of baffles.

16. The instrumented module was supported by a pin connection at the downstream end and a load cell at the upstream end as shown in Figure 7. The effect of spoilers with heights of 1, 2, and 3 ft located at the upstream and downstream end of the second row of baffles (Figure 7) was investigated. The dynamic forces acting on the upstream end of the module were detected by the load cell (Figure 7) and recorded on an oscillograph chart. A typical oscillograph record is shown in Figure 8. Analysis of the oscillograph records indicated that the forces occurred at a random frequency. The load cell was zeroed when the module was submerged with no flow as reflected by the zero datum shown in Figure 8. The average value of the forces acting on a unit width of the module is termed F_A and the maximum instantaneous force per foot of width is termed F_M.

17. Forces measured (per foot of module width) for 12 hydraulic conditions and various heights and locations of spoilers are tabulated in Table 1. Photographs of the 12 hydraulic conditions are shown in Photos 1-12. The maximum unit uplift forces are plotted versus unit discharge in Plate 3. The legend in Plate 3 relates the test curve to the basic data shown in Table 1. The plot indicates that the 1-ft-high spoiler located at the downstream end of the second row of baffles (Figure 9) provides the minimum amount of the uplift per foot of module width.

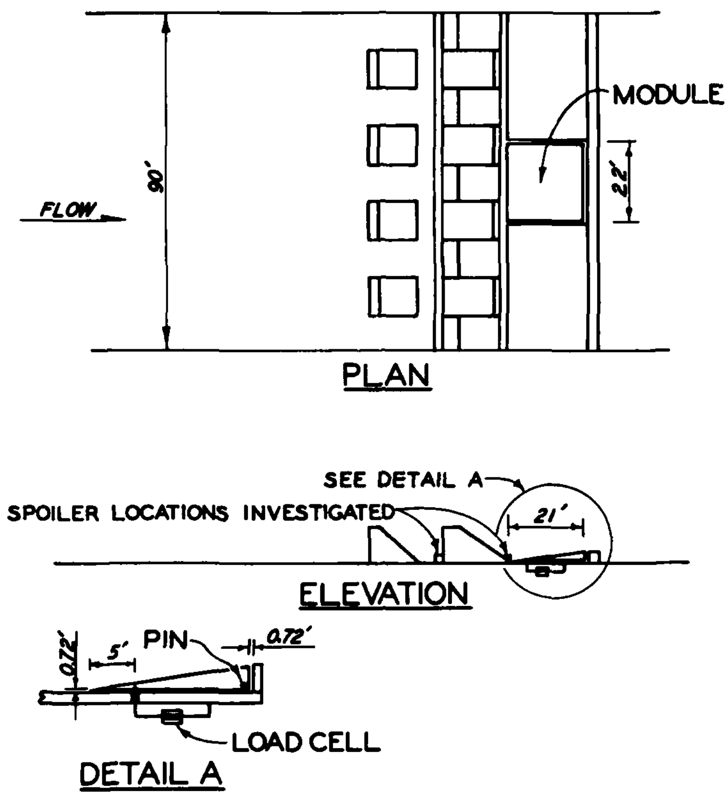


Figure 7. Spoiler test, instrumented module

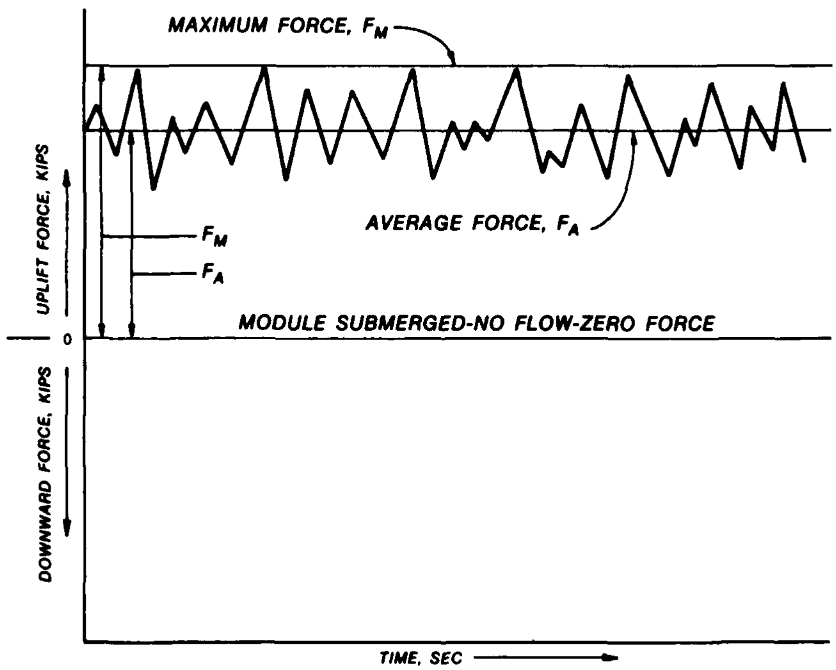


Figure 8. Typical oscillograph record for module tests

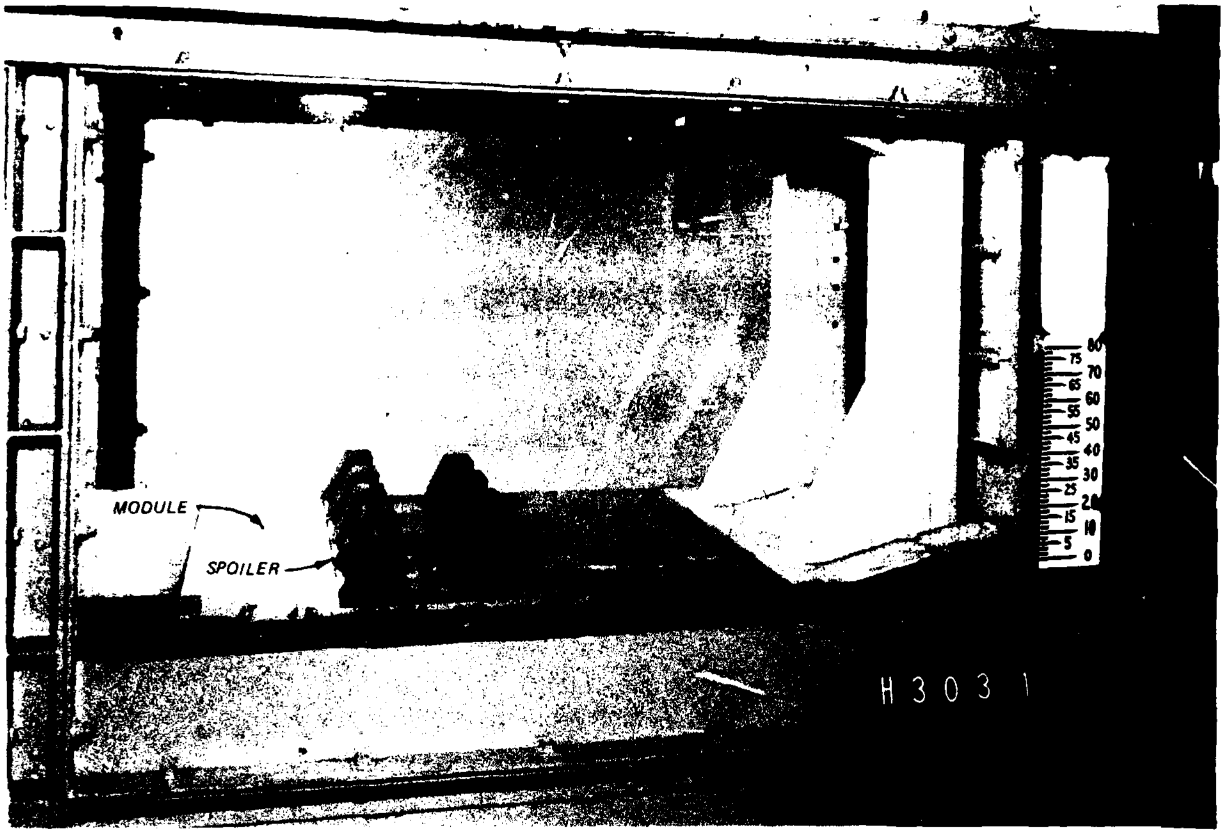


Figure 9. 1-ft-high spoiler, low bays

High bays

18. Tests were conducted with the high bays simulated to investigate the dynamic forces acting vertically (per foot of width) on the upstream end of the modules. Tests conducted with no spoilers and with 1-ft-high spoilers located at the downstream end of the second row of baffles showed reduced amounts of uplift on the module (Plate 4). Maximum and average forces per foot of module width measured for 19 hydraulic conditions with and without the 1-ft-high spoilers are presented in Table 2. A comparison (Plates 3 and 4) of the spoiler test results obtained with the low and high bays indicates that for given headwater and tailwater elevations the uplift forces on the modules downstream from the low bays are larger than those acting on the modules downstream from the high gate bays. This is attributed to the relatively greater depth and unit discharge of flow through the low gate bays.

Sliding and Uplift Hydraulic Forces Acting on the Stilling Basin

Low bays

19. Tests were conducted to investigate the vertical and horizontal dynamic forces acting (per foot of width) on the low bay portion of the stilling basin with no spoilers and with the 1-ft-high spoiler located at the downstream end of the baffles (best spoiler design).

20. Details of the 3.5-bay section model with the instrumented section is shown in Figure 10. The instrumented section (Figure 10) was designed to permit measurement of the magnitude, location, and direction of the resultant hydraulic forces acting on the stilling basin for various hydraulic conditions. To measure the vertical uplift F_V, the stilling basin was supported in the horizontal direction by ball bushings (Figure 10), and vertical forces were measured by strain Gages C and D (Figure 10). To measure the horizontal forces F_H, the stilling basin was supported in the vertical direction by roller bearings (Figure 10), and the horizontal forces were measured by strain Gages A and B (Figure 10).

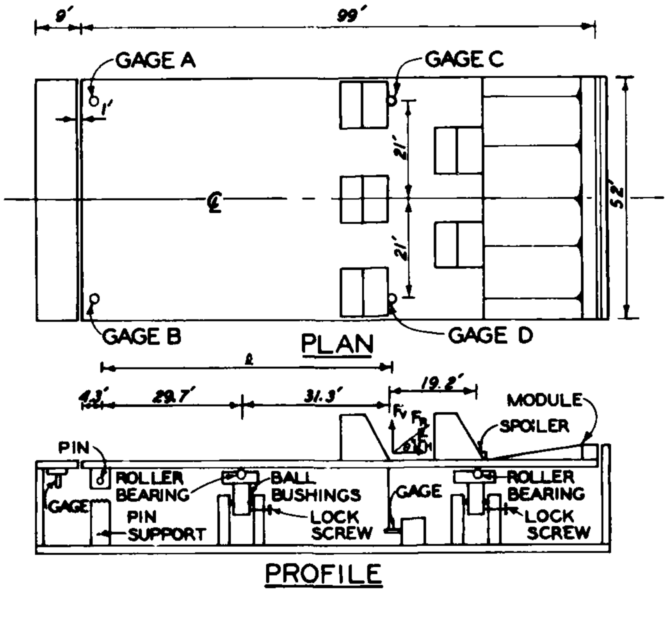


Figure 10. Stilling basin uplift tests, instrumented section

magnitude of the resultant force F_R was obtained by the following equation:

$$F_R = F_V^2 + F_H^2 \qquad (1)$$

The moment was obtained by supporting the stilling basin by strain Gages C and D and the pin. The moment about the pin is equal to the magnitude of the force measured by strain gages (C and D) times the distance from the pin to the strain gages (61 ft). The location ℓ of F_R was obtained by dividing the moment about the pin by F_V. The angle Θ to establish the direction of the resultant force was obtained by the following equation:

$$\tan \Theta = \frac{F_V}{F_H} \qquad (2)$$

Dynamic forces detected by the strain gages were recorded on an oscillograph chart as indicated by the typical oscillograph record shown in Figure 11. The strain gages were zeroed when the stilling basin was submerged with no flow as reflected by the zero datum in Figure 11. Analysis of the records indicated that the dynamic forces occurred at random frequency.

21. Maximum and average values of force per foot of stilling basin width, measured for various hydraulic conditions with various stilling basin elements, both with and without the best spoiler design are tabulated in Tables 3 and 4, respectively. The resultant forces and their respective locations are plotted versus unit discharge in Plates 5 and 6, respectively. As the unit discharge increases, the magnitude of the forces increases and the location of the resultant force generally varies from about 10 to 60 ft downstream from the pin (Plate 6). The data in Plate 5 also indicate that the spoiler had no significant effect on the magnitude of the forces. It is noted in Plate 5 that for a given unit flow rate the forces measured with the gates fully open tend to be less than those measured for gated flows. This is attributed to the fact that with the gates fully open there is a different flow pattern, less energy dissipation in the stilling basin, and higher velocities and greater scour potential in the downstream channel. The tabulated values in Tables 3 and 4 show that the resultant force F_R was always upward in a downstream direction (Figure 10) at an angle with the horizontal that usually varied between 30 and 60 deg. Tests conducted with the partial adjacent high bay gate in the model fully open or closed (Figure 4) indicated no

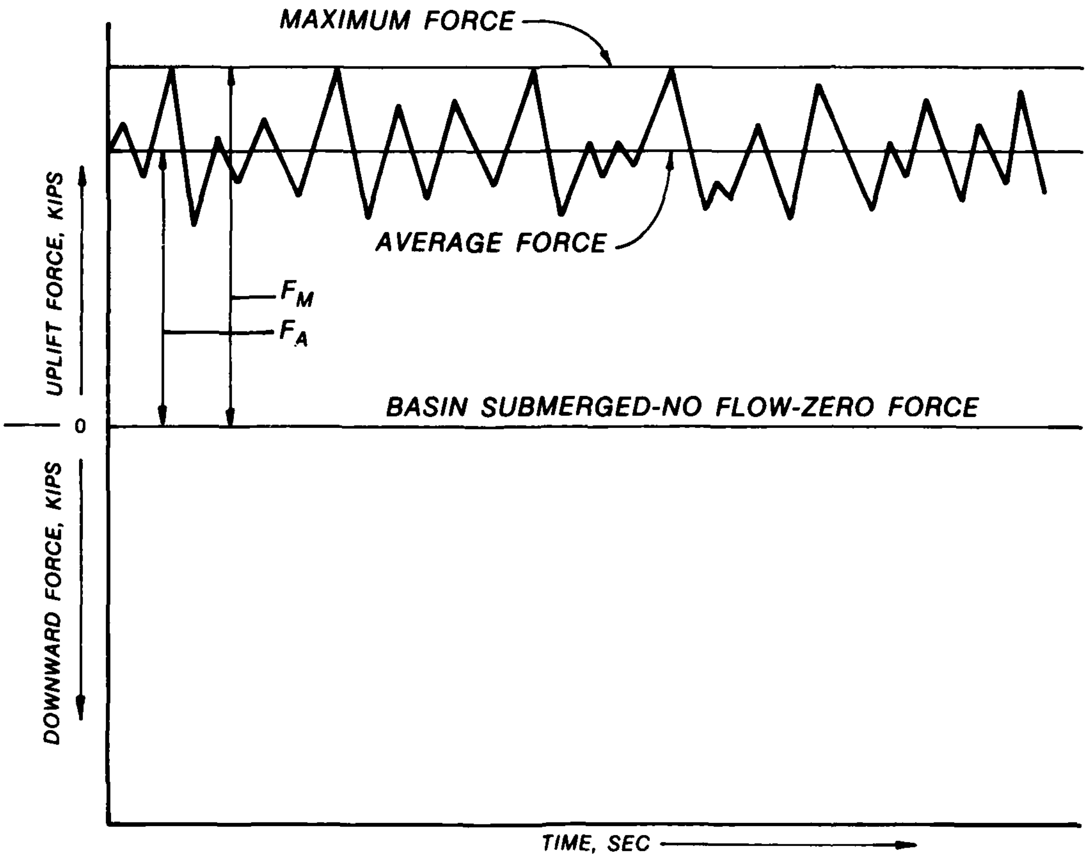


Figure 11. Typical oscillograph record for stilling basin uplift tests

significant difference on the hydraulic forces acting on the portion of the low bay that was instrumented.

22. The hydraulic conditions used for test 1 (Table 3) of the existing stilling basin without the best spoiler also were simulated to evaluate the stilling basin with the modules removed (Test 20, Table 3), with the front row of baffles removed (Test 21, Table 3), and with both rows of baffles removed (Test 22, Table 3). The results of these tests are tabulated in Table 3 and are included in the data plotted in Plates 5 and 6.

High bays

23. Tests were conducted to investigate the hydraulic forces acting on the high bay portion of the stilling basin (per foot of width). The instrumented section and procedure for measuring the forces and analyzing the data are identical to those described for the low bays.

24. The various hydraulic conditions investigated are shown in Photos 13-31. Maximum and average values of force per foot of stilling basin width are tabulated in Table 5. The tabulated values indicate that the resultant force was always upward and in a downstream direction. For given headwaters and tailwaters, the uplift forces acting on the stilling basin downstream from the low gate bays are larger than those acting on the portion of the basin downstream from the high gate bays. This is attributed to the relatively greater depth and higher unit discharge of flow through the low gate bays. Forces on the stilling basin were not significantly affected by the addition of the 1-ft-high spoilers.

Survey Boat Safety

25. Tests were conducted to evaluate various gated flow conditions that may be critical to the safety of a survey boat operating upstream of the high and low bay portions of the spillway. The model survey boat simulated the approximate length (30 ft) and width (8 ft) of a typical survey boat. The test results obtained from operation of the high and low bay portions of the structure are shown in Plates 7 and 8, respectively. With reference to the notations in Plates 7 and 8, the term "unsafe" signifies the overturning or passage of the boat beneath the gates; "questionably safe" indicates that the boat is unstable and subject to excessive rocking or listing; and "reasonably safe" signifies that the boat was stable upstream of the gates. Upstream and downstream views of the structure are shown in Photos 32 and 33. The data on Plates 7 and 8 indicate that a survey boat operating upstream of the high or low bays should be safe with gate openings equal to or less than 30 percent of the head on the crest.

Debris Passage

26. Tests were conducted with the high and low bays to determine the gate openings required for passage of debris. The debris used in the model simulated various sizes of logs up to a maximum length of 35 ft and a thickness of 3.0 ft. Results are shown in Plates 9 and 10. Flow conditions that do not and do permit debris passage are shown in Photos 32 and 33, respectively. Since the buoyancy, shape, and size of debris are variable, the

curves in Plates 9 and 10 are rough approximations. However, the data indicate that for the high and low bays some debris would pass with gage openings equal to about 30 to 40 percent of the head on the crest and that the chance for debris passage increases as the gate opening increases.

PART IV: DISCUSSION AND SUMMARY OF RESULTS

27. A hydraulic model investigation of the Old River Low-Sill Control Structure was conducted to (a) investigate the feasibility of rehabilitating the portion of the stilling basin apron between the baffle piers and end sill; (b) develop guidance relative to survey boat safety, and (c) determine gate openings necessary for debris passage.

28. The apron between the baffle piers and end sill was overlaid with modules, and tests were conducted to determine the uplift forces on the modules. To reduce uplift on the module, 1-ft-high spoilers were installed at the downstream end of the second row of baffles. Test results indicated that the uplift forces acting on the module downstream from the low bays with or without the spoilers are larger than those acting on the module downstream from the high gate bays. The higher uplift forces were attributed to the relatively greater depth and unit discharge of flow through the low gate bays.

29. Test results indicated that the addition of the 1-ft-high spoilers had no significant effect on the sliding or uplift forces acting on the stilling basin.

30. Tests conducted to evaluate survey boat safety indicated that a survey boat operating upstream of the gate bays should be safe with gate openings equal to or less than 30 percent of the head on the crest.

31. Tests conducted to evaluate debris passage indicated that debris up to 35 ft long and 3.0 ft thick would pass through the structure with gate openings equal to about 30 to 40 percent of the head on the crest.

Table 1

Uplift Forces Acting on Module Per Foot of Width, Low Bays

Test No.	Differential Head ft	Headwater ft NGVD	Tailwater ft NGVD	Gate Opening ft	Unit Discharge cfs/ft	Average Force kips/ft	Maximum Force kips/ft	Flow Conditions	Spoiler Location and Height
1	16	60	44	36.19	970	0.35	1.52	Submerged controlled orifice flow	
2		50	34	36.19	1,030	0.50	1.83	Submerged controlled orifice flow	
3		40	24	28.94	743	0.49	1.60	Submerged controlled orifice flow	
4		30	14	19.28	514	0.19	1.30	Free controlled orifice flow	
5		20	4	14.65	345	0.23	0.90	Free controlled orifice flow	
6	22	60	38	36.19	1,100	0.61	2.20	Submerged controlled orifice flow	
7	22	50	28	36.19	1,067	0.61	2.10	Free controlled orifice flow	
8	22	40	18	28.94	757	0.47	1.60		
9	22	30	8	19.28	520	0.15	1.10		
10	37	60	23	36.19	1,216	0.65	2.60		
11	37	50	13	36.19	1,081	0.38	1.40		
12	37	40	9	28.94	770	0.0	1.12		

(Continued)

Note: All forces act in an upward direction unless indicated otherwise.

(Sheet 1 of 7)

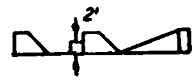
Table 1 (Continued)

Test No.	Differential Head ft	Headwater ft NGVD	Tailwater ft NGVD	Gate Opening ft	Unit Discharge cfs/ft	Average Force kips/ft	Maximum Force kips/ft	Flow Conditions	Spoiler Location and Height
1A	16	60	44	36.19	970	0.53	1.80	Submerged controlled orifice flow	
2A		50	34	36.19	1,030	0.91	1.80	Submerged controlled orifice flow	
3A		40	24	28.94	743	0.57	1.70	Submerged controlled orifice flow	
4A		30	14	19.28	514	0.23	0.80	Free controlled orifice flow	
5A		20	4	14.65	345	0.30	0.70	Free controlled orifice flow	
6A	22	60	38	36.19	1,100	0.84	2.30	Submerged controlled orifice flow	
7A	22	50	28	36.19	1,067	0.76	2.60	Free controlled orifice flow	
8A	22	40	18	28.94	757	0.38	1.50		
9A	22	30	8	19.28	520	0.31	1.40		
10A	37	60	23	36.19	1,216	0.92	2.70		
11A	37	50	13	36.19	1,081	0.61	2.40		
12A	37	40	9	28.94	770	0.38	1.30		

(Continued)

(Sheet 2 of 7)

Table 1 (Continued)

Test No.	Differential Head ft	Headwater ft NGVD	Tailwater ft NGVD	Gate Opening ft	Unit Discharge cfs/ft	Average Force kips/ft	Maximum Force kips/ft	Flow Conditions	Spoiler Location and Height
1B	16	60	44	36.19	970	0.45	1.70	Submerged controlled orifice flow	
2B		50	34	36.19	1,030	0.69	2.30	Submerged controlled orifice flow	
3B		40	24	28.94	743	0.46	2.10	Submerged controlled orifice flow	
4B		30	14	19.28	514	0.53	1.10	Free controlled orifice flow	
5B		20	4	14.65	345	0.30	1.20	Free controlled orifice flow	
6B	22	60	38	36.19	1,100	0.76	2.40	Submerged controlled orifice flow	
7B	22	50	28	36.19	1,067	0.95	2.20	Free controlled orifice flow	
8B	22	40	18	28.94	757	0.54	2.30		
9B	22	30	8	19.28	520	0.30	1.50		
10B	37	60	23	36.19	1,216	0.80	2.30		
11B	37	50	13	36.19	1,081	0.61	2.10		
12B	37	40	9	28.94	770	0.45	2.20		

(Continued)

(Sheet 3 of 7)

Table 1 (Continued)

Test No.	Differential Head ft	Headwater ft NGVD	Tailwater ft NGVD	Gate Opening ft	Unit Discharge cfs/ft	Average Force kips/ft	Maximum Force kips/ft	Flow Conditions	Spoiler Location and Height
1C	16	60	44	36.19	970	0.15	1.06	Submerged controlled orifice flow	
2C		50	34	36.19	1,030	0.30	1.53	Submerged controlled orifice flow	
3C		40	24	28.94	743	0.27	1.02	Submerged controlled orifice flow	
4C		30	14	19.28	514	0.30	0.69	Free controlled orifice flow	
5C		20	4	14.65	345	-0.10*	0.57	Free controlled orifice flow	
6C	22	60	38	36.19	1,100	0.23	2.03	Submerged controlled orifice flow	
7C	22	50	28	36.19	1,067	0.38	1.33	Free controlled orifice flow	
8C	22	40	18	28.94	757	0.19	1.14		
9C	22	30	8	19.28	520	0.30	0.69		
10C	37	60	23	36.19	1,216	0.19	1.90		
11C	37	50	13	36.19	1,081	0.19	1.00		
12C	37	40	9	28.94	770	0.38	0.76		

(Continued)

* - Indicates force acts in a downward direction.

(Sheet 4 of 7)

Table 1 (Continued)

Test No.	Differential Head ft	Headwater ft NGVD	Tailwater ft NGVD	Gate Opening ft	Unit Discharge cfs/ft	Average Force kips/ft	Maximum Force kips/ft	Flow Conditions	Spoiler Location and Height
1D	16	60	44	36.19	970	-0.04*	0.50	Submerged controlled orifice flow	
2D		50	34	36.19	1,030	0.07	0.76	Submerged controlled orifice flow	
3D		40	24	28.94	743	-0.07*	0.53	Submerged controlled orifice flow	
4D		30	14	19.28	514	-0.19*	0.45	Free controlled orifice flow	
5D		20	4	14.65	345	-0.38*	0.07	Free controlled orifice flow	
6D	22	60	38	36.19	1,100	-0.07*	0.69	Submerged controlled orifice flow	
7D	22	50	28	36.19	1,067	0.15	0.84	Free controlled orifice flow	
8D	22	40	18	28.94	757	-0.04*	0.64		
9D	22	30	8	19.28	520	-0.30*	0.30		
10D	37	60	23	36.19	1,216	-0.07*	0.69		
11D	37	50	13	36.19	1,081	0.15	0.72		
12D	37	40	9	28.94	770	-0.23*	0.38		

(Continued)

* - Indicates force acts in a downward direction.

(Sheet 5 of 7)

Table 1 (Continued)

Test No.	Differential Head ft	Headwater ft NGVD	Tailwater ft NGVD	Gate Opening ft	Unit Discharge cfs/ft	Average Force kips/ft	Maximum Force kips/ft	Flow Conditions	Spoiler Location and Height
1E	16	60	44	36.19	970	0.23	0.61	Submerged controlled orifice flow	
2E		50	34	36.19	1,030	0.27	0.80	Submerged controlled orifice flow	
3E		40	24	28.94	743	0.23	0.69	Submerged controlled orifice flow	
4E		30	14	19.28	514	-0.09*	0.49	Free controlled orifice flow	
5E		20	4	14.65	345	-0.27*	0.30	Free controlled orifice flow	
6E	22	60	38	36.19	1,100	0.27	0.88	Submerged controlled orifice flow	
7E	22	50	28	36.19	1,067	0.34	0.95	Free controlled orifice flow	
8E	22	40	18	28.94	757	0.23	0.88		
9E	22	30	8	19.28	520	-0.15*	0.49		
10E	37	60	23	36.19	1,216	0.0	0.53		
11E	37	50	13	36.19	1,081	0.0	0.58		
12E	37	40	9	28.94	770	0.0	0.58		

(Continued)

* - Indicates force acts in a downward direction.

(Sheet 6 of 7)

Table 1 (Concluded)

Test No.	Differential Head ft	Headwater ft NGVD	Tailwater ft NGVD	Gate Opening ft	Unit Discharge cfs/ft	Average Force kips/ft	Maximum Force kips/ft	Flow Conditions	Spoiler Location and Height
1F	16	60	44	36.19	970	0.23	0.61	Submerged controlled orifice flow	
2F		50	34	36.19	1,030	0.38	0.91	Submerged controlled orifice flow	
3F		40	24	28.94	743	0.23	0.68	Submerged controlled orifice flow	
4F		30	14	19.28	514	0.08	0.53	Free controlled orifice flow	
5F		20	4	14.65	345	-0.19*	0.23	Free controlled orifice flow	
6F	22	60	38	36.19	1,100	0.26	0.72	Submerged controlled orifice flow	
7F	22	50	28	36.19	1,067	0.38	1.15	Free controlled orifice flow	
8F	22	40	18	28.94	757	0.34	0.91		
9F	22	30	8	19.28	520	-0.04*	0.49		
10F	37	60	23	36.19	1,216	0.30	0.95		
11F	37	50	13	36.19	1,081	0.80	0.50		
12F	37	40	9	28.94	770	0.07	0.76		

* - Indicates force acts in a downward direction.

(Sheet 7 of 7)

Table 2

Uplift Forces Acting on Module Per Foot of Width, High Bays

Test No.	Differential Head ft	Head-water ft NGVD	Tail-water ft, NGVD	Gate Opening ft	Unit Discharge cfs/ft	Average Force kips/ft	Maximum Force kips/ft	Flow Condition	Spoiler Location and Height
23	16	60	44	24.86	635	0.12	0.42	Submerged controlled orifice flow	
24		50	34	19.28	568	0.23	0.46	Submerged controlled orifice flow	
25		40	24	14.65	405	0.12	0.24	Free controlled orifice flow	
26		30	14	7.36	110	0.07	0.18	Free controlled orifice flow	
27		20	4	4.20	76	0.07	0.13	Free controlled orifice flow	
28	22	60	38	24.86	743	0.25	0.75	Submerged controlled orifice flow	
29	22	50	28	19.28	554	0.27	0.51	Free controlled orifice flow	
30	22	40	18	14.65	423	0.14	0.31		
31	22	30	8	7.36	176	0.15	0.30		
32	37	60	23	24.86	811	0.47	1.05		
33	37	50	13	19.28	554	0.24	0.48		
34	37	40	3	14.65	419	0.17	0.51		
35	5	60	55	36.19	649	0.07	0.28	Submerged controlled orifice flow	
36		50	45	28.94	554	0.20	0.44		
37		40	35	19.28	351	0.05	0.09		
38		30	25	11.36	184	0.06	0.11		
39		20	15	4.20	68	-0.03	0.00		
40	16	52	36	Fully open	1,216	0.80	1.36	Gates are fully open	
41	10	52	42	Fully open	1,108	0.23	0.63	Gates are fully open	
23A	16	60	44	24.86	635	0.03	0.14	Submerged controlled orifice flow	
24A		50	34	19.28	568	0.04	0.08	Submerged controlled orifice flow	
25A		40	24	14.65	405	0.04	0.06	Free controlled orifice flow	
26A		30	14	7.36	110	-0.02	0.00	Free controlled orifice flow	
27A		20	4	4.20	76	-0.04	0.00	Free controlled orifice flow	
28A	22	60	38	24.86	743	0.05	0.15	Submerged controlled orifice flow	
29A	22	50	28	19.28	554	0.06	0.13	Free controlled orifice flow	
30A	22	40	18	14.65	423	0.07	0.07		
31A	22	30	8	7.36	176	-0.12	0.00		
32A	37	60	23	24.86	811	0.08	0.27		
33A	37	50	13	19.28	554	0.06	0.27		
34A	37	40	3	14.65	419	0.02	0.19		
35A	5	60	55	36.19	649	0.04	0.11	Submerged controlled orifice flow	
36A		50	45	28.94	554	0.03	0.11		
37A		40	35	19.28	351	0.02	0.05		
38A		30	25	11.36	184	0.00	0.02		
39A		20	15	4.20	68	-0.02	0.00		
40A	16	52	36	Fully open	1,216	0.01	0.31	Gages are fully open	
41A	10	52	42	Fully open	1,108	0.06	0.18	Gates are fully open	

Note: All forces act in a upward direction unless indicated otherwise.
- Indicates force acts in a downward direction.

Table 3

Magnitude, Location, and Direction of Average and Maximum External Hydraulic Forces Acting on Stilling Basin per Foot of Basin Width, Existing Design, Low Bays

						Average Force per Foot of Stilling Basin Width						Maximum Force per Foot of Stilling Basin Width							
Test No.	Head-water ft	Tail-water ft	Differential Head ft	Gate Opening ft	Unit Dis-charge cfs/ft	Verti-cal kips	Hori-zontal kips	Moment About Pin kips/ft	Resultant Force kips	Resultant Location ft	Resultant Angle deg	Verti-cal kips	Hori-zontal kips	Moment About Pin kips/ft	Resultant Force kips	Resultant Location ft	Resultant Angle deg	Flow Conditions	Design
1	60	44	16	36.19	970	10.3	9.9	520	14.3	51	51.3	11.8	11.9	720	16.8	61	44.8	Submerged controlled orifice flow	
2	50	34		36.19	1,030	8.6	9.3	350	12.7	40	47.5	9.9	10.6	490	14.5	50	43.0	Submerged controlled orifice flow	
3	40	24		28.94	743	6.3	7.9	170	10.1	27	42.9	10.2	9.7	300	14.1	28	46.4	Submerged controlled orifice flow	
4	30	14		19.28	514	3.4	6.0	34	6.9	10	32.8	7.6	7.0	127	10.3	17	47.4	Free controlled orifice flow	
5	20	4		14.65	345	0.4	3.6	2.5	3.62	6	7.0	1.2	4.2	55	4.4	46	16.0	Free controlled orifice flow	
6	60	38	22	36.19	1,100	13.4	11.6	610	17.7	45	54.6	18.3	14.8	730	21.5	40	51.2	Submerged controlled orifice flow	
7	50	28	22	36.19	1,067	10.7	10.2	350	14.8	33	51.5	14.1	11.9	550	18.5	39	49.9	Free controlled orifice flow	
8	40	18	22	28.94	757	5.8	8.6	150	10.4	26	37.8	11.7	10.1	310	15.5	27	49.2		
9	30	8	22	19.28	520	4.6	6.5	31	8.0	7	39.2	8.0	7.7	152	8.5	19	46.1		
10	60	23	37	36.19	1,216	12.8	13.7	200	18.8	16	47.8	16.0	15.9	390	22.6	24	45.2		
11	50	13	37	36.19	1,081	8.6	11.8	85	14.6	10	40.1	14.3	13.2	270	19.5	19	47.3		
12	40	9	37	28.94	770	7.5	8.9	85	11.6	11	44.6	13.4	10.0	204	16.7	15	53.3		
13	60	55	5	47.15	750	2.5	3.6	160	4.4	64	53.4	4.0	4.8	220	6.2	55	39.1	Submerged controlled orifice flow	
14	50	45		36.19	590	4.7	4.6	160	6.6	34	50.7	5.3	5.2	230	7.4	44	45.6		
15	40	35		32.69	550	3.5	3.1	100	4.7	29	53.9	4.6	3.7	152	5.9	33	51.2		
16	30	25		24.86	535	3.1	3.2	72	4.5	24	49.0	4.3	3.7	122	5.7	28	49.3		
17	20	15		14.65	250	2.3	1.7	8.5	2.9	4	59.4	3.4	2.0	34	3.9	10	59.5		
18	52	40	12	Fully open	1,660	2.0	4.7	65	5.1	33	32.0	2.9	5.4	100	6.1	34	28.0	Gates are fully open	
19	50	35	15	Fully open	1,640	1.8	7.2	60	7.4	33	21.2	2.8	8.4	120	8.8	43	33.0	Gates are fully open	
20	60	44	16	36.19	970	6.4	9.0	320	11.0	50	35.4	9.2	16.4	430	18.8	47	29.3	Submerged controlled orifice flow	
21	60	44	16	36.19	970	14.4	6.7	830	15.9	58	65.0	17.0	7.0	980	18.4	58	67.6	Submerged controlled orifice flow	
22	60	44	16	36.19	970	17.9	0.8	510	17.9	29	87.4	20.0	3.6	680	20.3	34	79.8	Submerged controlled orifice flow	

Note: All vertical forces are acting in an upward direction. All horizontal forces are acting in a downstream direction.

Table 4

Magnitude, Location, and Direction of Average and Maximum External Hydraulic Forces Acting on Stilling basin per Foot of Basin Width,

1-Ft-High Spoiler, Low Bays

						Average Force per Foot of Stilling Basin Width						Maximum Force per Foot of Stilling Basin Width							
Test No.	Head-water ft	Tail-water ft	Differential Head ft	Gate Opening ft	Unit Dis-charge cfs/ft	Verti-cal kips	Hori-zontal kips	Moment About Pin kips/ft	Resultant Force kips	Resultant Location ft	Resultant Angle deg	Verti-cal kips	Hori-zontal kips	Moment About Pin kips/ft	Resultant Force kips	Resultant Location ft	Resultant Angle deg	Flow Conditions	Design
1	60	44	16	36.19	970	9.0	14.0	305	16.6	33	33	11.0	18.3	454	21.3	41	31	Submerged controlled orifice flow	
2	50	34		36.19	1,083	8.5	9.3	413	12.6	49	42	10.2	10.6	592	14.7	58	44	Submerged controlled orifice flow	
3	40	24		28.94	743	7.0	7.2	190	10.0	28	44	9.5	8.1	324	12.5	34	50	Submerged controlled orifice flow	
4	30	14		19.28	514	3.5	5.5	102	6.5	29	32	7.2	6.5	175	9.7	24	48	Free controlled orifice flow	
5	20	4		14.65	345	0.8	3.1	23	3.2	28	14	1.4	3.5	64	3.8	45	22	Free controlled orifice flow	
6	60	38	22	36.19	1,100	13.6	11.8	525	18.0	39	49	16.5	16.9	763	23.6	46	44	Submerged controlled orifice flow	
7	50	28	22	36.19	1,067	10.1	10.6	407	14.6	41	43	13.2	13.4	610	18.8	46	45	Free controlled orifice flow	
8	40	18	22	28.94	757	6.1	10.2	110	11.9	18	31	12.0	11.6	240	16.7	20	46		
9	30	8	22	19.28	520	4.3	6.1	70	7.5	16	35	7.0	7.0	159	9.9	22	45		
10	60	23	37	36.19	1,216	11.5	16.7	224	20.2	20	34	16.0	19.9	451	25.5	28	39		
11	50	13	37	36.19	1,081	9.1	12.3	34	15.3	13	37	13.6	13.9	232	19.4	17	44		
12	40	8	37	28.94	770	8.3	9.3	110	12.5	13.2	42	12.3	11.0	268	16.5	22	48		
13	60	55	5	47.15	750	3.0	4.0	161	5.0	54	37	4.0	4.4	222	5.9	55	42	Submerged controlled orifice flow	
14	50	45		36.19	590	4.6	6.8	137	8.2	30	34	5.1	7.6	201	9.1	41	34		
15	40	35		32.69	550	3.4	3.1	103	4.6	30	47	4.4	3.5	165	5.6	36	52		
16	30	25		24.86	535	3.0	3.8	71	4.8	24	38	4.0	4.1	104	5.8	26	44		
17	20	15		14.65	250	2.6	1.5	31	3.0	12	60	3.6	1.7	57	4.0	16	65		
18	52	40	12	Fully open	1,660	2.2	5.9	80	6.3	36	20	2.5	7.1	115	7.5	46	19	Gates are fully open	
19	50	35	15	Fully open	1,640	5.0	7.1	278	8.7	70	35	8.0	7.7	440	11.1	55	46	Gates are fully open	

Note: All vertical forces are acting in an upward direction. All horizontal forces are acting in a downstream direction.

Table 5

Magnitude, Location, and Direction of Average and Maximum External Hydraulic Forces Acting on Stilling Basin per Foot of Basin Width,

Existing Design, High Bays

						Average Force per Foot of Stilling Basin Width						Maximum Force per Foot of Stilling Basin Width							
Test No.	Headwater ft	Tailwater ft	Differential Head ft	Gate Opening ft	Unit Discharge cfs/ft	Vertical kips	Horizontal kips	Moment About Pin kips/ft	Resultant Force kips	Resultant Location ft	Resultant Angle deg	Vertical kips	Horizontal kips	Moment About Pin kips/ft	Resultant Force kips	Resultant Location ft	Resultant Angle deg	Flow Conditions	Design
23	60	44	16	24.86	635	4.0	5.5	350	6.8	88.0	36.0	5.1	5.1	420	7.2	82	44.9	Submerged controlled orifice flow	
24	50	34		19.28	568	3.9	5.2	340	6.5	87.5	36.8	4.8	5.6	350	7.4	73	40.6	Submerged controlled orifice flow	
25	40	24		14.65	405	5.3	3.4	187	6.3	35.0	57.3	6.3	3.9	425	7.4	67	58.1	Free controlled orifice flow	
26	30	14		7.36	110	4.6	1.5	83	4.8	18.0	71.9	5.4	1.7	156	5.7	29	75.5	Free controlled orifice flow	
27	20	4		4.20	76	2.9	0.1	88	2.9	30.4	88.0	2.0	0.6	60	2.1	30	72.0	Free controlled orifice flow	
28	60	38	22	24.86	743	7.0	5.0	478	8.6	68.0	54.5	8.8	5.5	611	10.4	69	57.9	Submerged controlled orifice flow	
29	50	28	22	19.28	554	4.9	12.1	270	13.0	55.1	22.0	6.2	12.6	392	14.0	63	26.2	Free controlled orifice flow	
30	40	18	22	14.65	423	3.2	6.3	120	7.1	37.0	26.9	3.6	6.7	246	7.6	68	28.4		
31	10	8	22	7.36	176	1.8	1.6	46	2.4	24.9	48.4	3.2	1.9	132	3.7	41	58.6		
32	60	23	37	24.86	811	8.8	14.1	616	16.6	70.2	32.0	9.5	15.6	817	18.3	86	31.4		
33	50	13	37	19.28	554	2.0	14.2	117	14.4	8.3	8.0	2.6	14.9	73	15.1	28	9.9		
34	40	3	37	14.65	419	1.0	7.9	192	8.0	66.5	7.2	1.5	8.2	50	8.3	33	10.4		
35	60	55	5	36.19	649	1.8	3.4	151	3.6	84.0	27.9	2.3	3.8	192	4.4	83	31.2	Submerged controlled orifice flow	
36	50	45		28.94	554	2.2	3.9	184	4.5	83.4	29.4	3.1	4.4	261	5.4	83	35.2		
37	40	35		19.28	351	1.3	1.4	113	1.9	85.3	42.9	1.9	1.6	166	2.5	85	50.0		
38	30	25		11.36	184	1.7	0.8	74	1.9	42.4	64.8	2.4	1.0	129	2.6	54	67.4		
39	20	15		4.20	68	0.6	0.1	33	0.6	58.8	80.5	0.9	0.2	55	0.9	61	74.5		
40	52	36	16	Fully open	1,216	6.4	6.0	570	8.8	88.3	46.8	7.8	6.3	659	10.0	84	51.0	Gates are fully open	
41	52	42	10	Fully open	1,108	5.0	2.7	411	5.7	82.0	61.6	7.1	3.0	505	7.7	71	67.1	Gates are fully open	

Note: All vertical forces are acting in an upward direction. All horizontal forces are acting in a downstream direction.

Photo 1. Hydraulic condition low bays = headwater el 60 ft, tailwater el 44 ft, gate opening 36.19 ft

Photo 2. Hydraulic condition low bays = headwater el 50 ft, tailwater el 34 ft, gate opening 36.19 ft

Photo 3. Hydraulic condition low bays = headwater el 40.0 ft, tail-water el 24.0 ft, gate opening 28.94 ft

Photo 4. Hydraulic condition low bays = headwater el 30 ft, tail-water el 14 ft, gate opening 19.28 ft

Photo 5. Hydraulic condition low bays = headwater el 20 ft, tailwater el 4 ft, gate opening 14.65 ft

Photo 6. Hydraulic condition low bays = headwater el 60 ft, tailwater el 38 ft, gate opening 36.19 ft

Photo 7. Hydraulic condition low bays = headwater el 50 ft, tailwater el 28 ft, gate opening 36.19 ft

Photo 8. Hydraulic condition low bays = headwater el 40 ft, tailwater el 18 ft, gate opening 28.94 ft

Photo 9. Hydraulic condition low bays = headwater el 30.0 ft, tailwater el 8.0 ft, gate opening 19.28 ft

Photo 10. Hydraulic condition low bays = headwater el 60 ft, tailwater el 23 ft, gate opening 36.19 ft

Photo 11. Hydraulic condition low bays = headwater el 50 ft, tailwater el 13 ft, gate opening 36.19 ft

Photo 12. Hydraulic condition low bays = headwater el 40 ft, tailwater el 9 ft, gate opening 28.94 ft

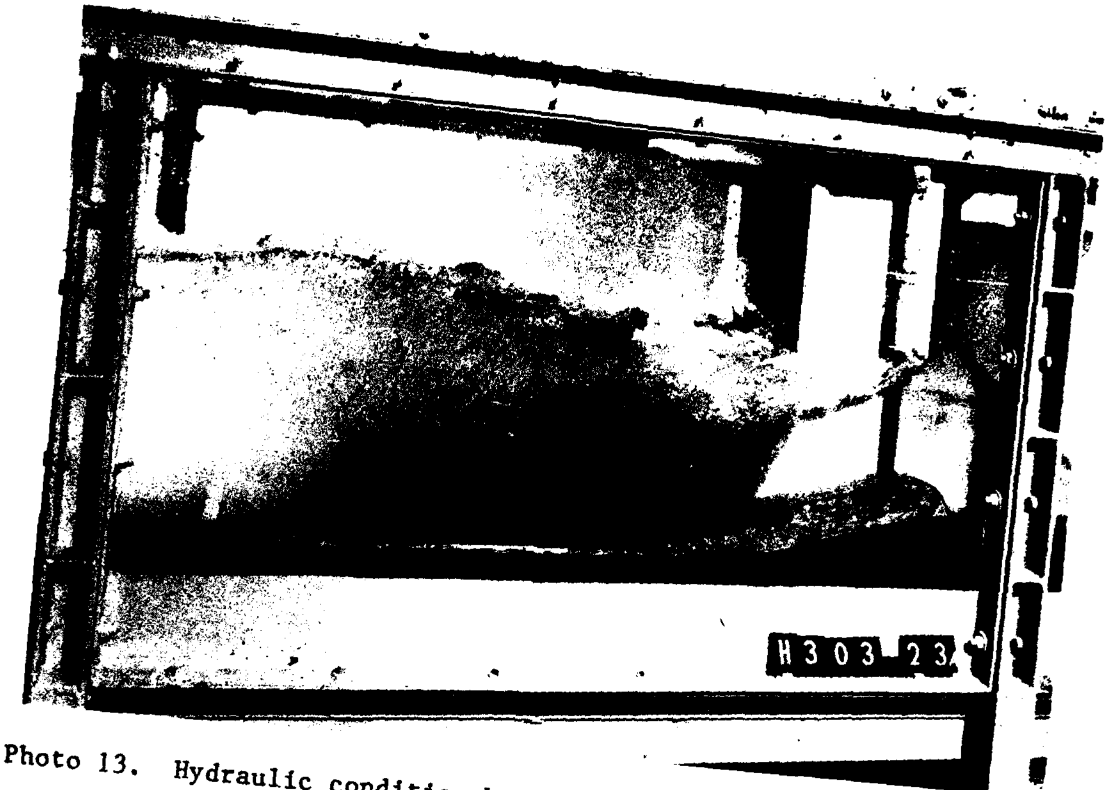


Photo 13. Hydraulic condition high bays = headwater el 60 ft, tailwater el 44 ft, gate opening 24.86 ft

Photo 14. Hydraulic condition high bays = headwater el 50 ft, tailwater el 34 ft, gate opening 19.28 ft

Photo 15. Hydraulic condition high bays = headwater el 40 ft, tail-water el 24 ft, gate opening 14.65 ft

Photo 16. Hydraulic condition high bays = headwater el 30 ft, tail-water el 14 ft, gate opening 7.36 ft

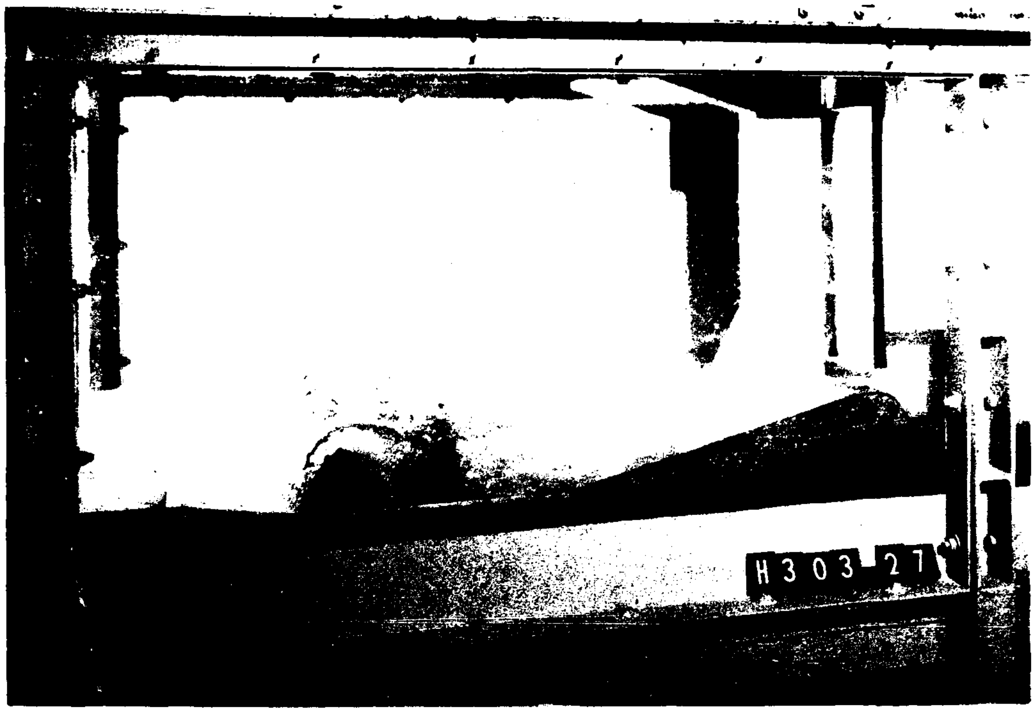


Photo 17. Hydraulic condition high bays = headwater el 20 ft, tailwater el 4 ft, gate opening 4.2 ft

Photo 18. Hydraulic condition high bays = headwater el 60 ft, tailwater el 38 ft, gate opening 24.86 ft

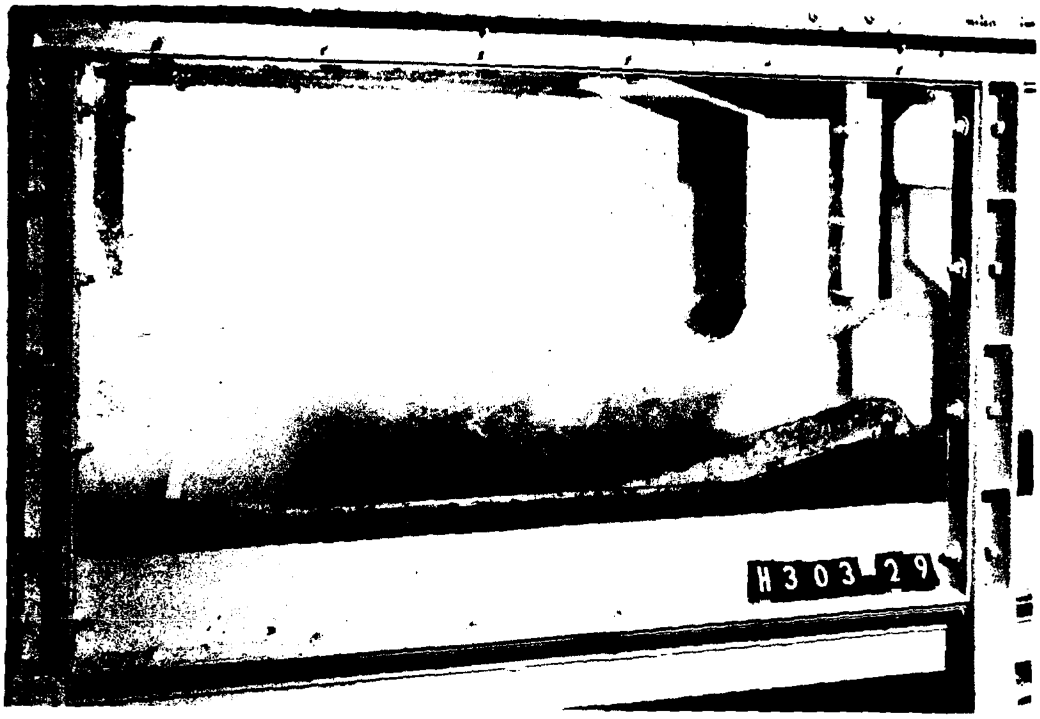


Photo 19. Hydraulic condition high bays = headwater el 50 ft, tailwater el 28 ft, gate opening 19.28 ft

Photo 20. Hydraulic condition high bays = headwater el 40 ft, tailwater el 18 ft, gate opening 14.65 ft

Photo 21. Hydraulic condition high bays = headwater el 30 ft, tailwater el 8 ft, gate opening 7.36 ft

Photo 22. Hydraulic condition high bays = headwater el 60 ft, tailwater el 23 ft, gate opening 24.86 ft

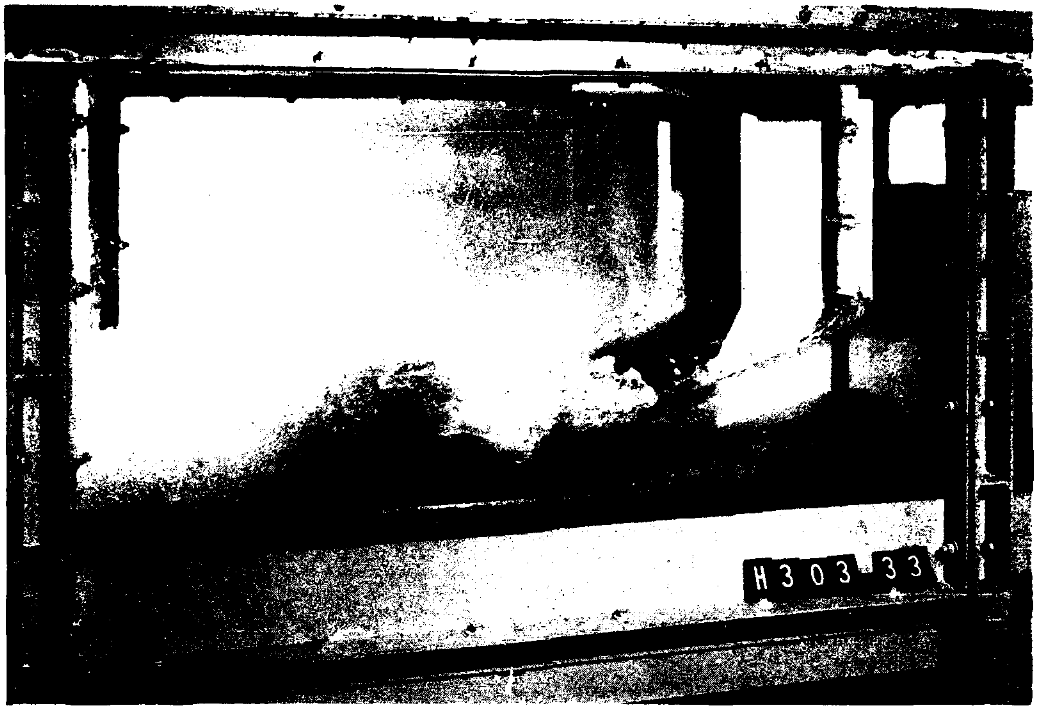


Photo 23. Hydraulic condition high bays = headwater el 50 ft, tail-water el 13 ft, gate opening 19.28 ft

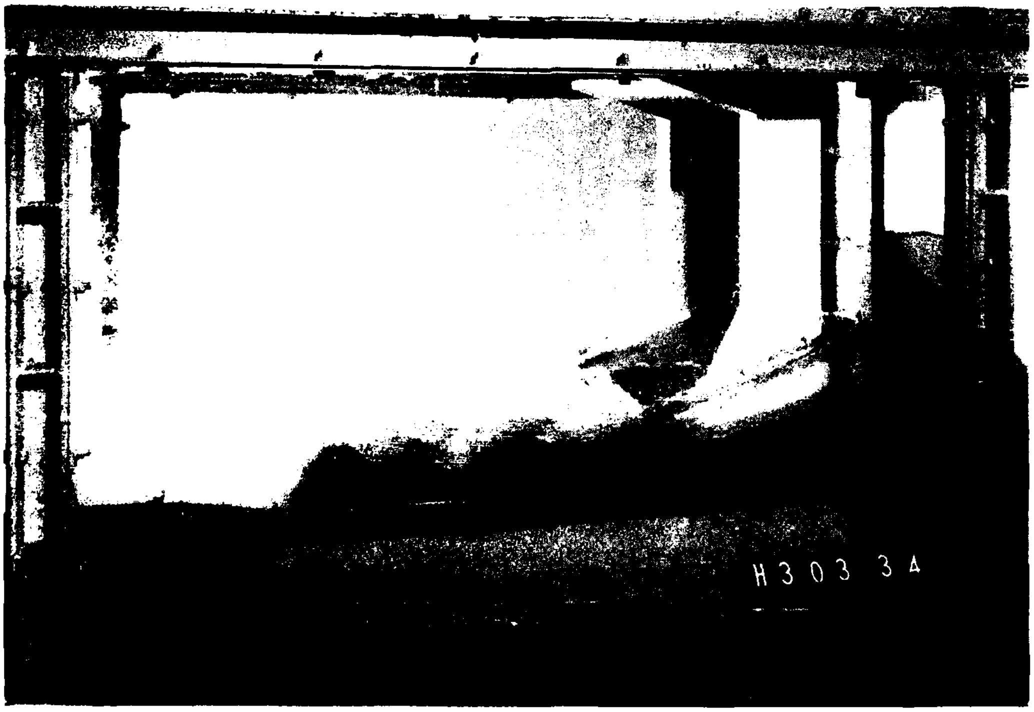


Photo 24. Hydraulic condition high bays = headwater el 40 ft, tail-water el 8 ft, gate opening 14.65 ft

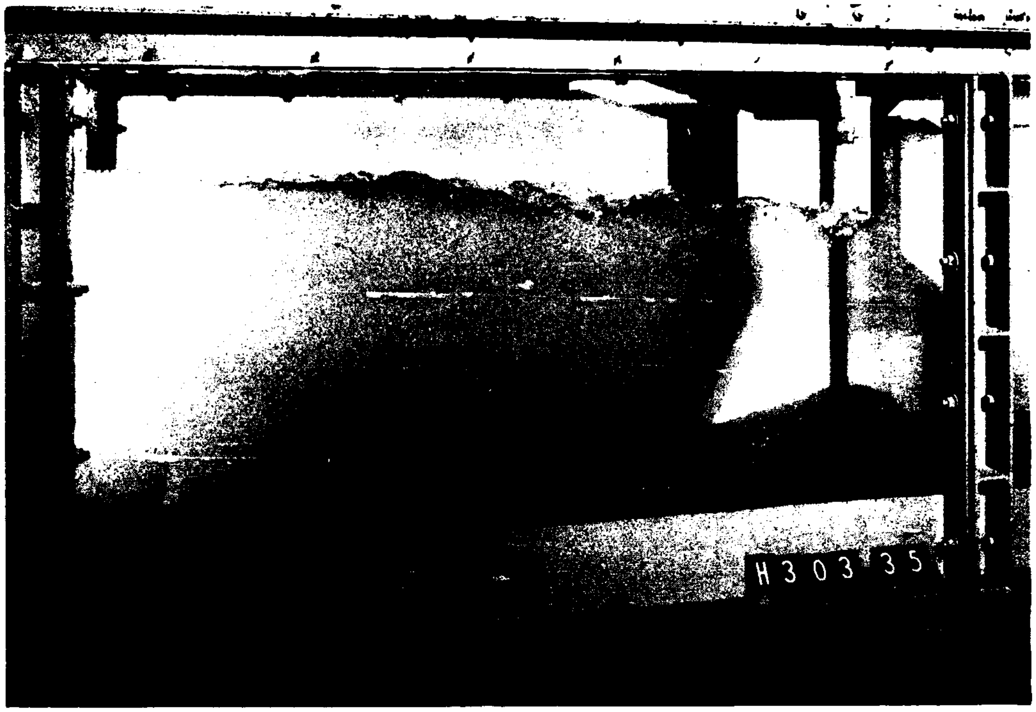


Photo 25. Hydraulic condition high bays = headwater el 60 ft, tailwater el 55 ft, gate opening 36.19 ft

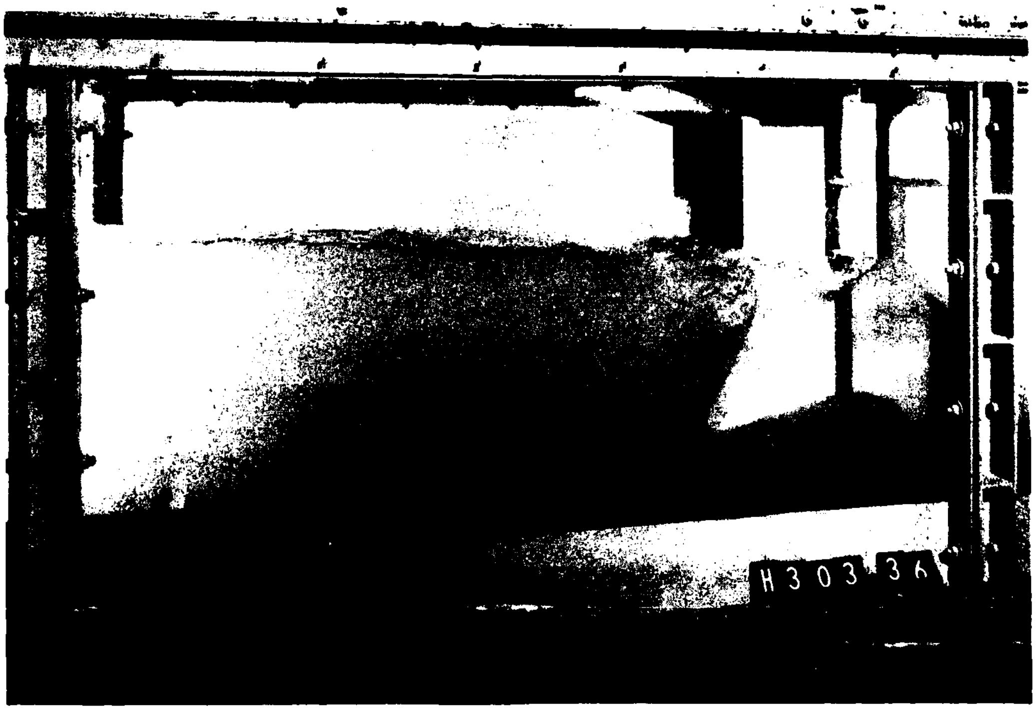


Photo 26. Hydraulic condition high bays = headwater el 50 ft, tailwater el 45 ft, gate opening 28.94 ft

Photo 27. Hydraulic condition high bays = headwater el 40 ft, tailwater el 35 ft, gate opening 19.28 ft

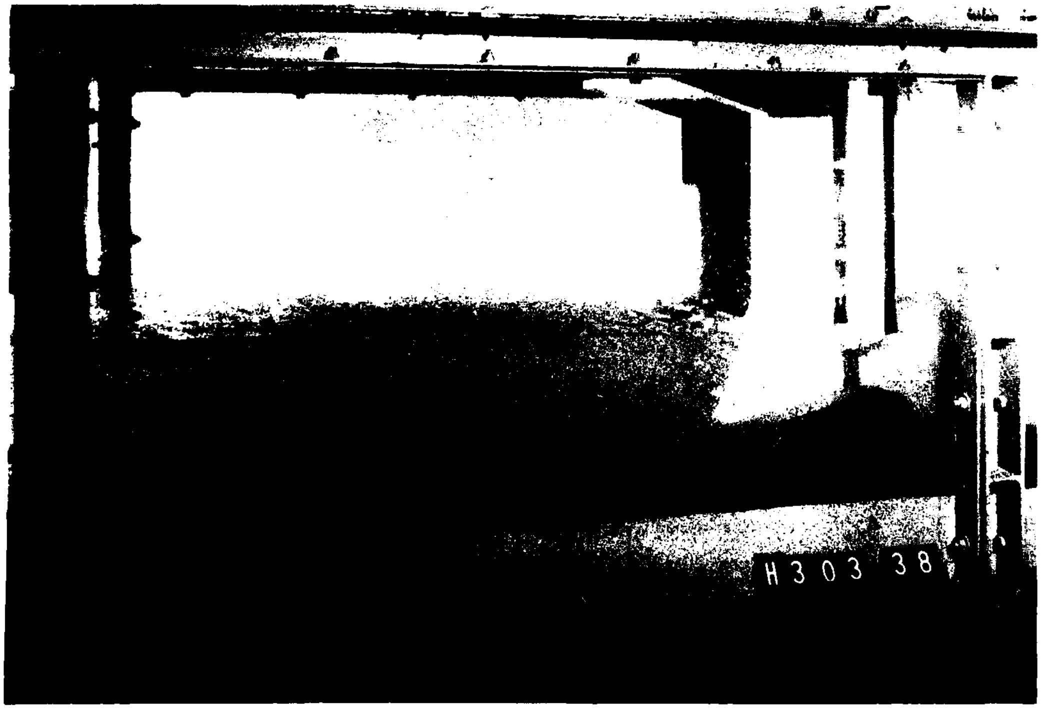


Photo 28. Hydraulic condition high bays = headwater el 30 ft, tailwater el 25 ft, gate opening 11.36 ft

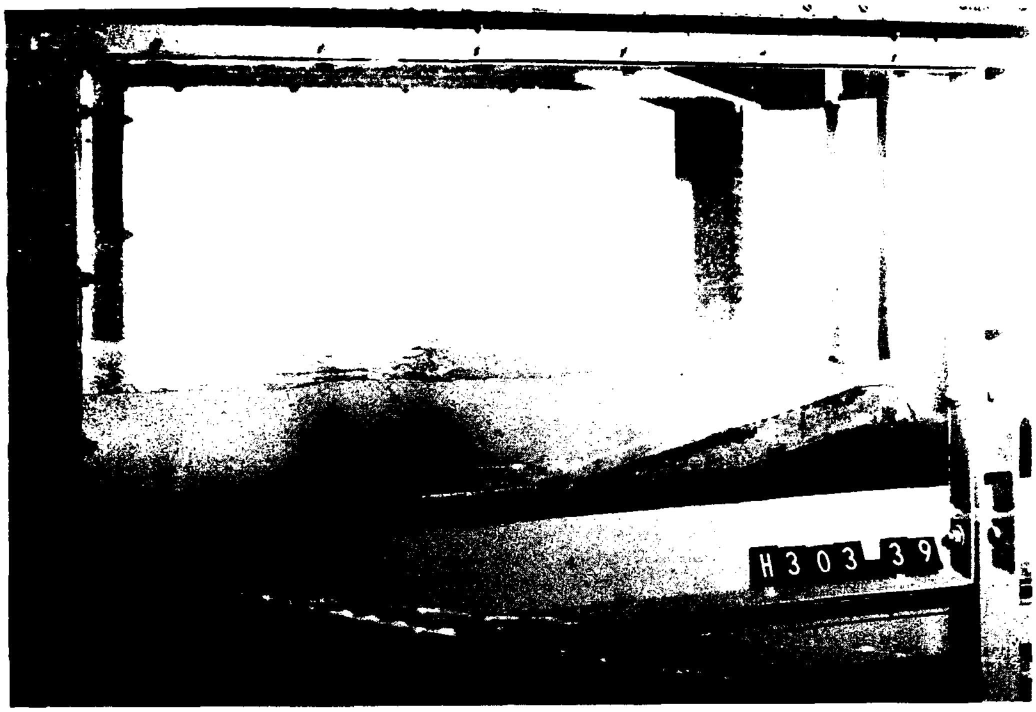


Photo 29. Hydraulic condition high bays = headwater el 20 ft, tail-water el 15 ft, gate opening 4.20 ft

Photo 30. Hydraulic condition high bays = headwater el 52 ft, tail-water el 36 ft, gate opening fully open

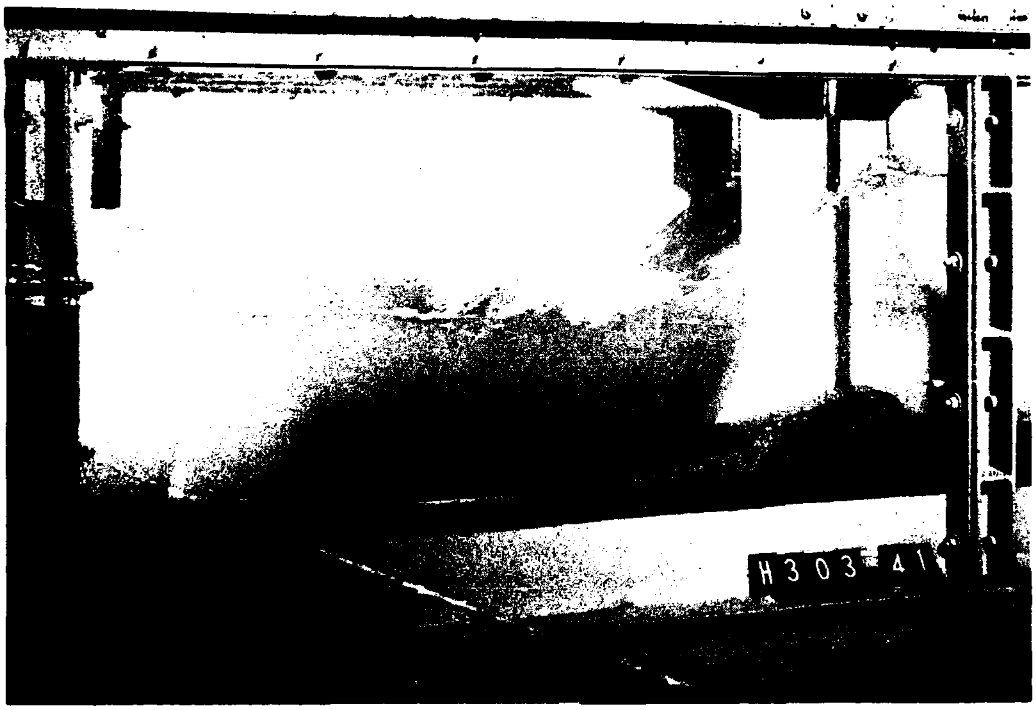
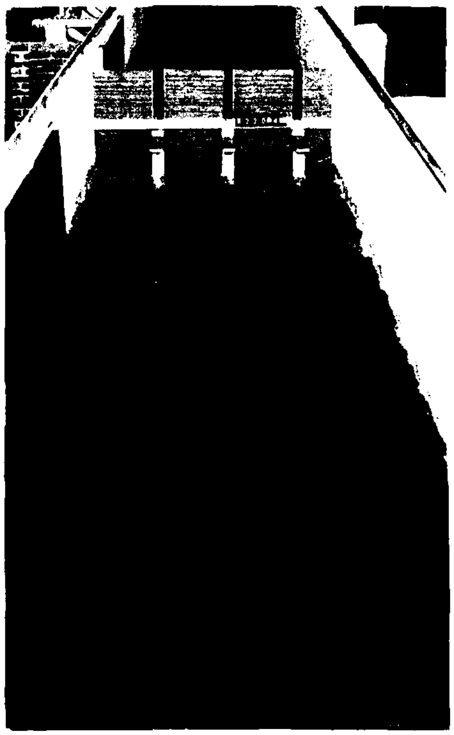


Photo 31. Hydraulic condition high bays = headwater el 52 ft, tail-water el 42 ft, gate opening fully open

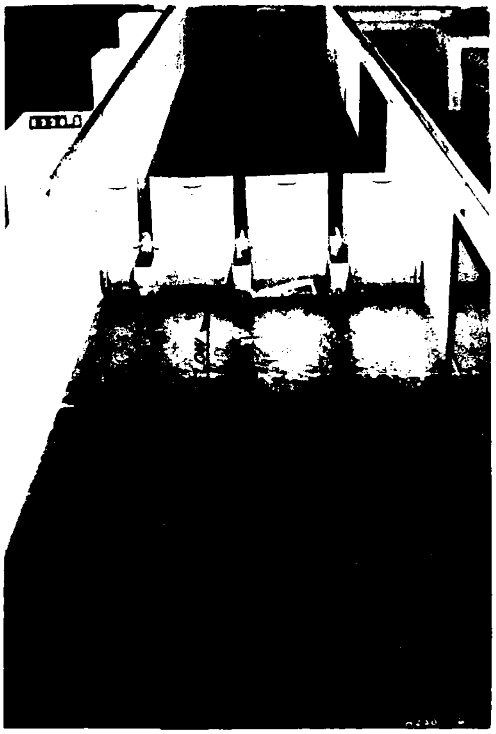
a. View from upstream

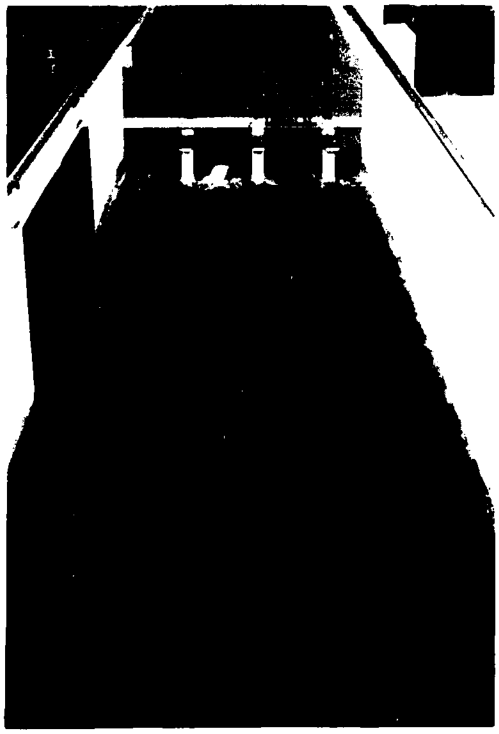


b. View from downstream

Photo 32. Survey boat safety and debris passage. Boat did not capsize. Debris did not pass. Gate opening = 30 ft, pool el = 60 ft, tailwater el = 50 ft

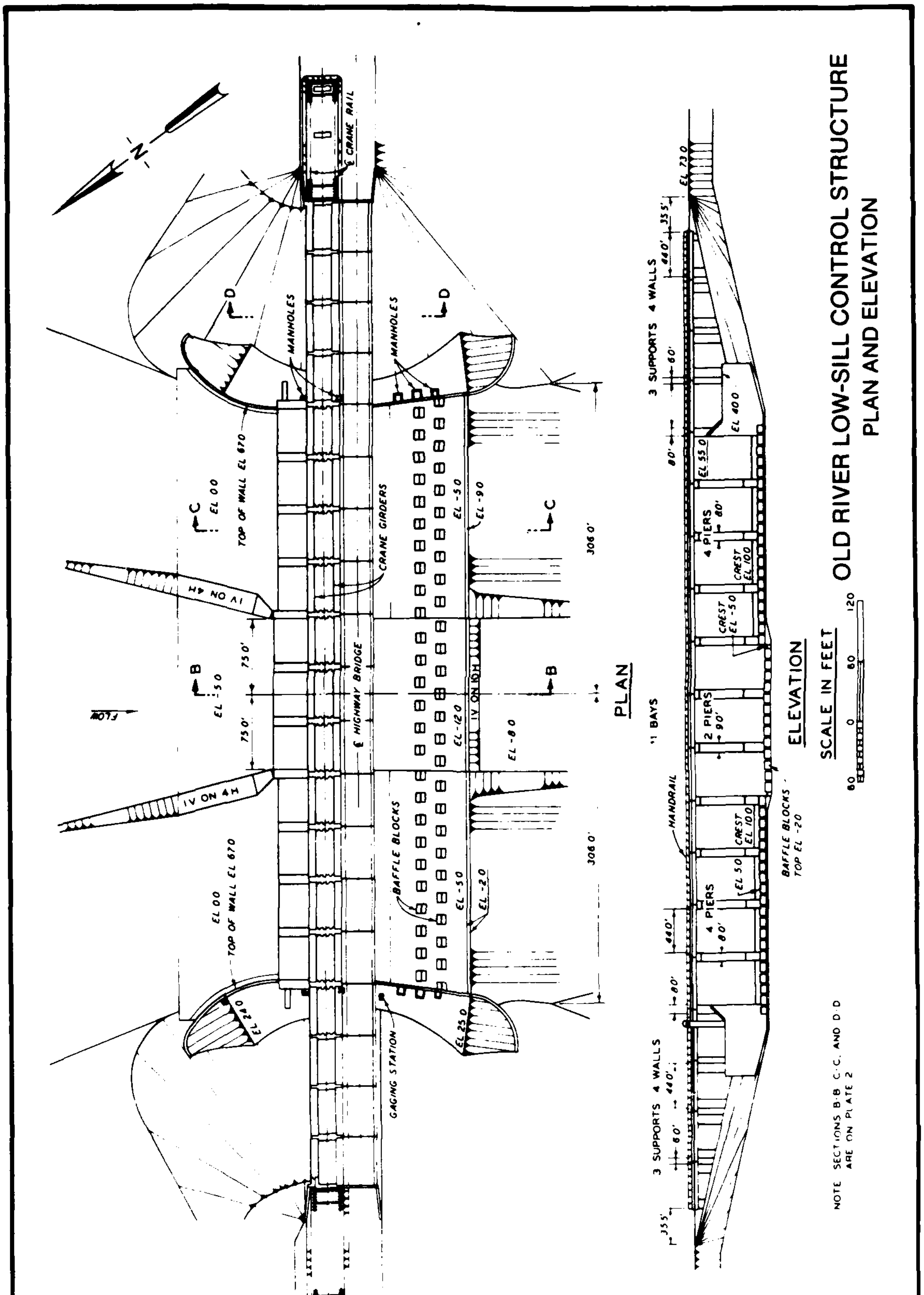
a. View from upstream

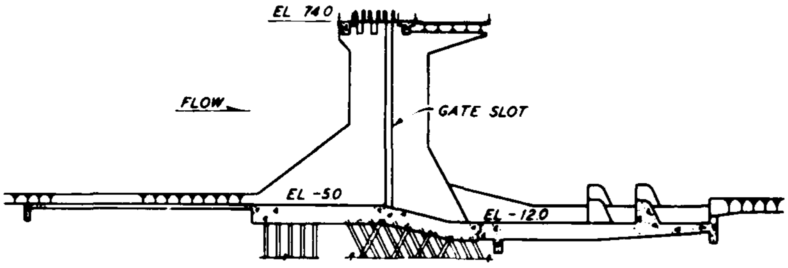




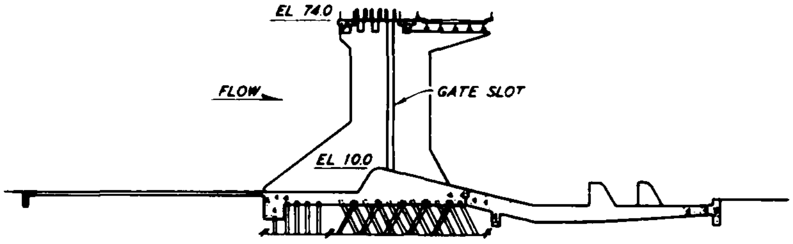
b. View from downstream

Photo 33. Survey boat safety and debris passage. Boat capsize. Debris passed. Gate opening = 30 ft, pool el = 51 ft, tailwater el = 44 ft

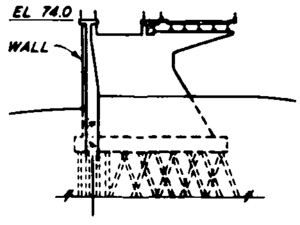

OLD RIVER LOW-SILL CONTROL STRUCTURE
PLAN AND ELEVATION
PLAN
ELEVATION
SCALE IN FEET
80 0 80 120
FLOW
CRANE RAIL
MANHOLES
CRANE GIRDERS
HIGHWAY BRIDGE
BAFFLE BLOCKS
GAGING STATION
TOP OF WALL EL 67.0
EL 0.0
1V ON 4H
3 SUPPORTS 4 WALLS
4 PIERS
2 PIERS
HANDRAIL
BAFFLE BLOCKS TOP EL -2.0
11 BAYS
NOTE SECTIONS B-B, C-C, AND D-D ARE ON PLATE 2



SECTION B–B

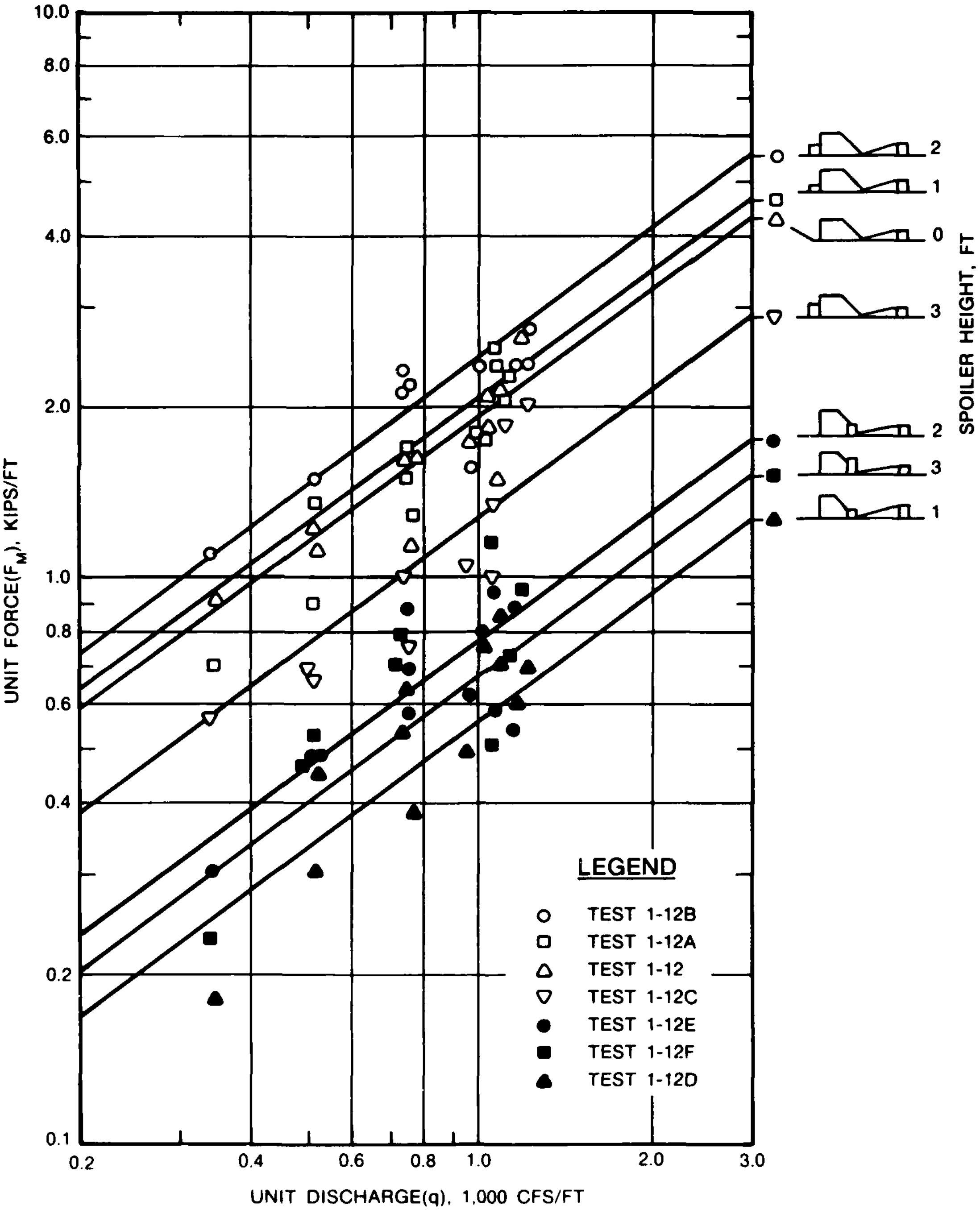


SECTION C–C

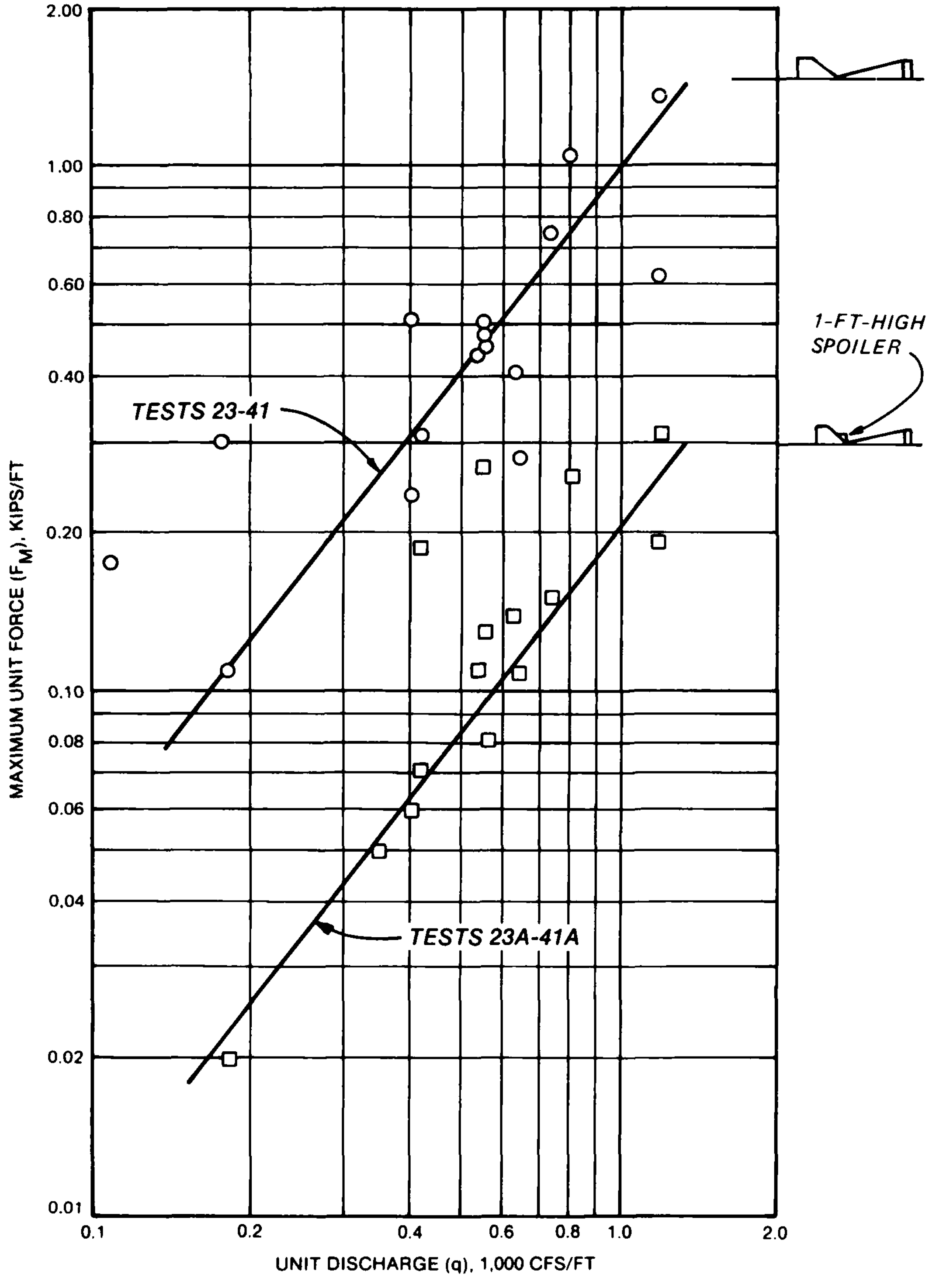


SECTION D–D

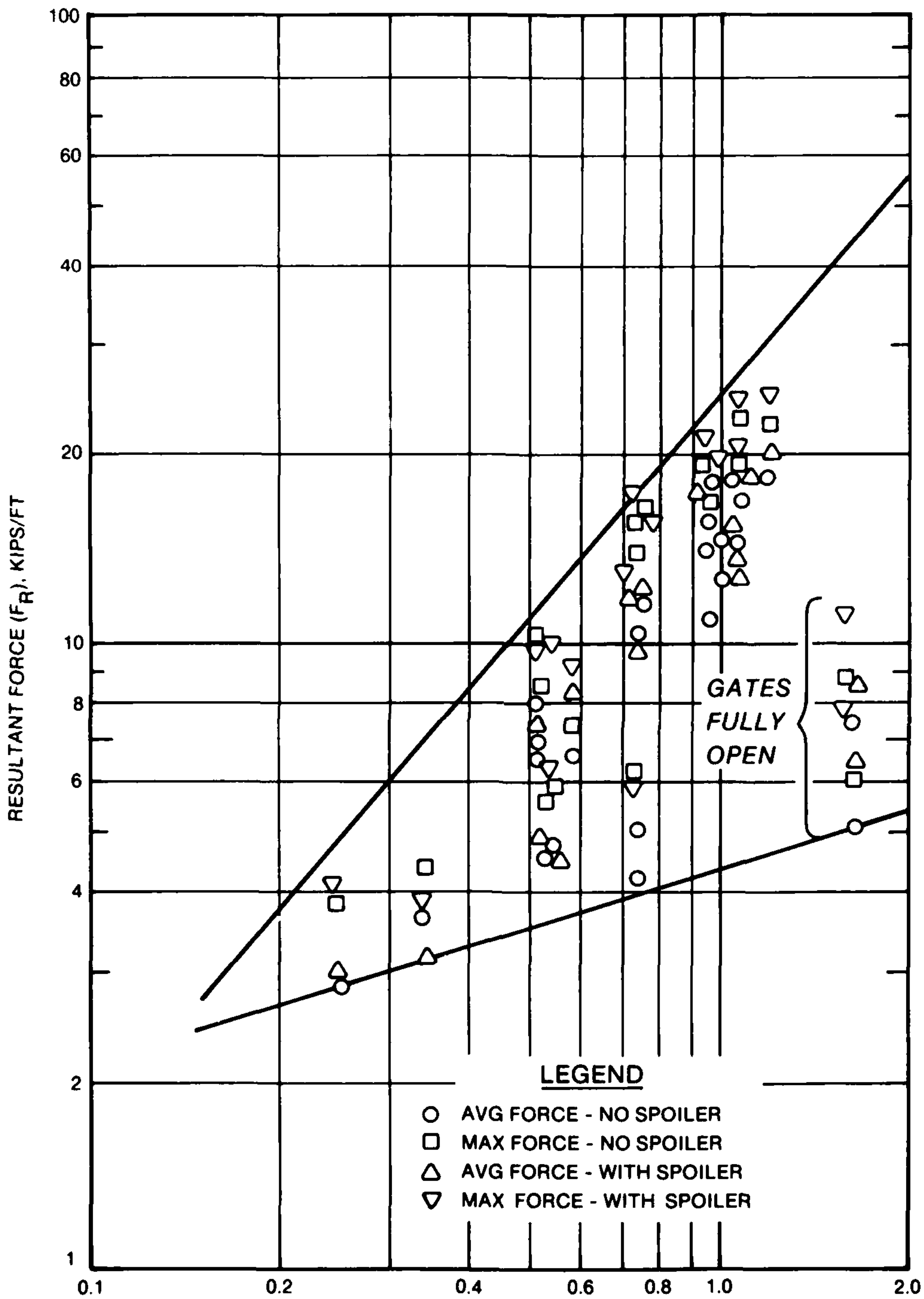
OLD RIVER
LOW-SILL CONTROL STRUCTURE
PIERS



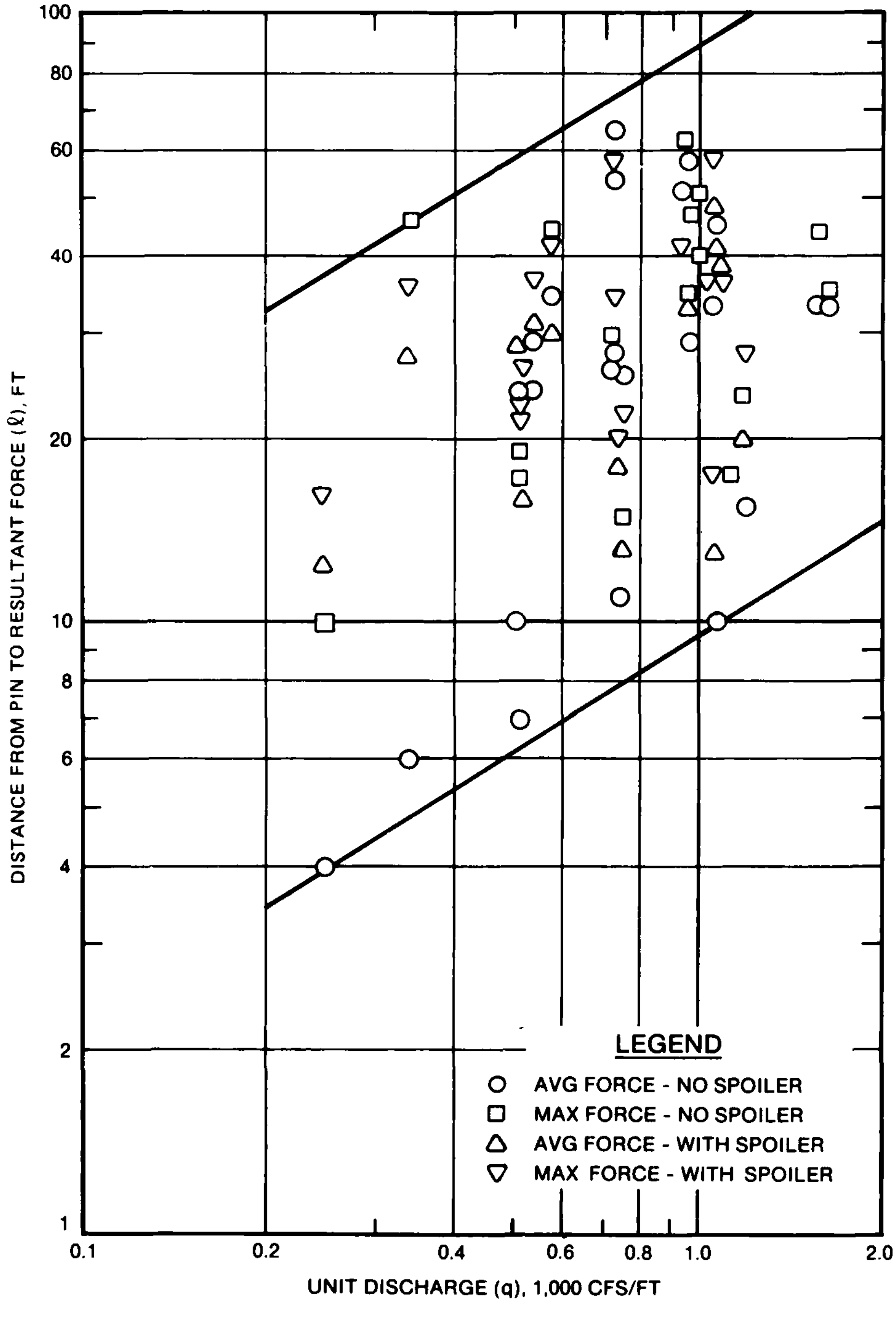
SPOILER TESTS
DYNAMIC UPLIFT FORCES PER FOOT
OF MODULE WIDTH, TESTS 1-12
OLD RIVER LOW-SILL



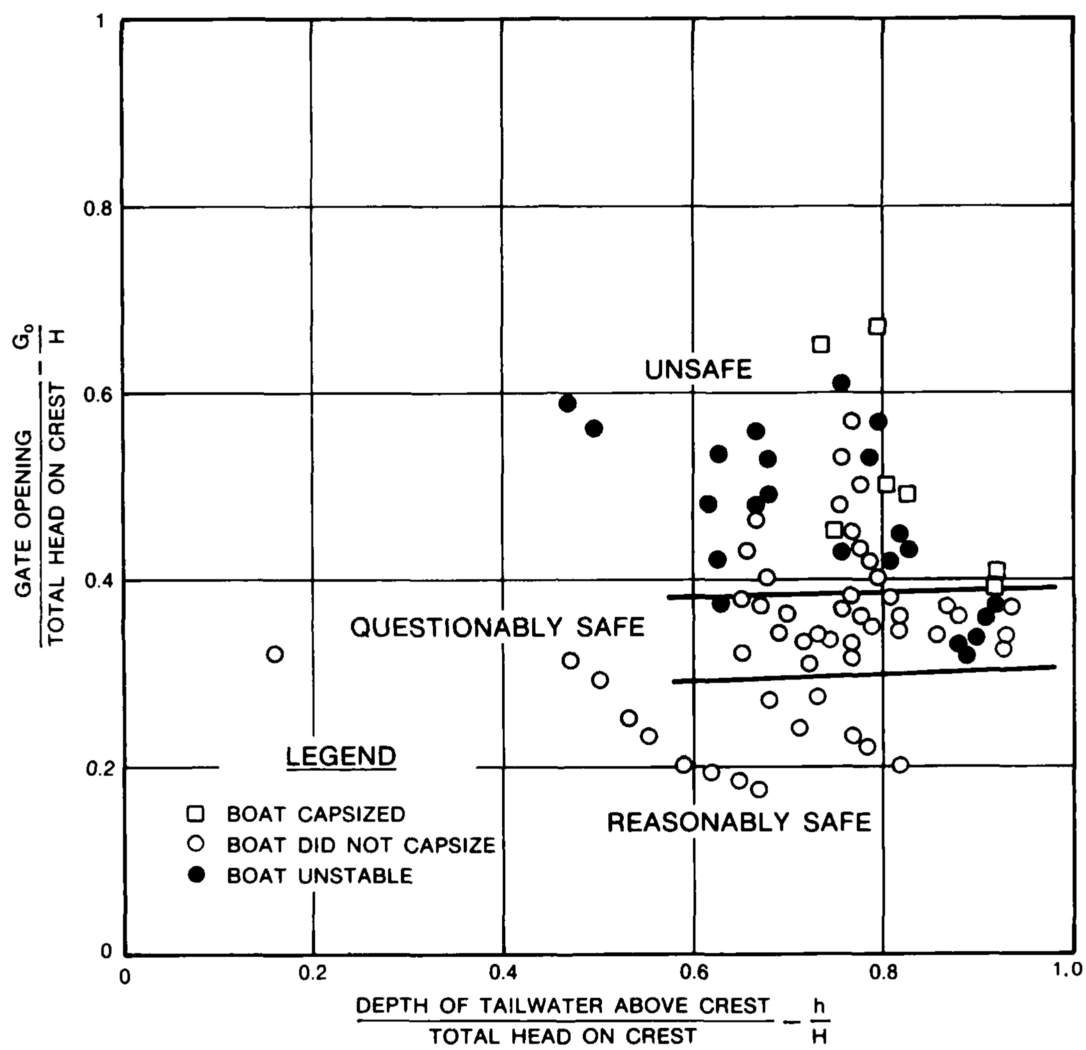
SPOILER TESTS
DYNAMIC UPLIFT FORCES PER FOOT
OF MODULE WIDTH, TESTS 23-41



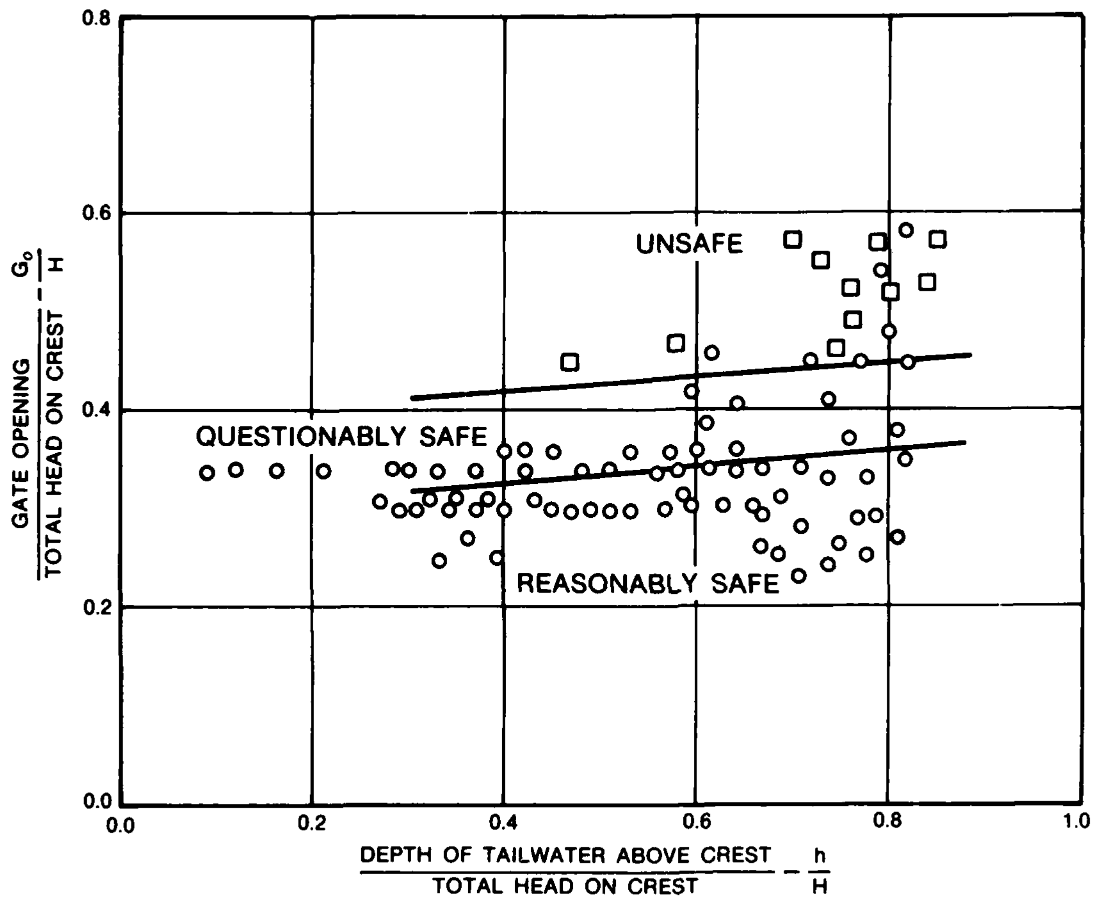
STILLING BASIN UPLIFT TESTS
RESULTANT DYNAMIC UPLIFT FORCES, LOW BAYS
PER FOOT OF STILLING BASIN WIDTH



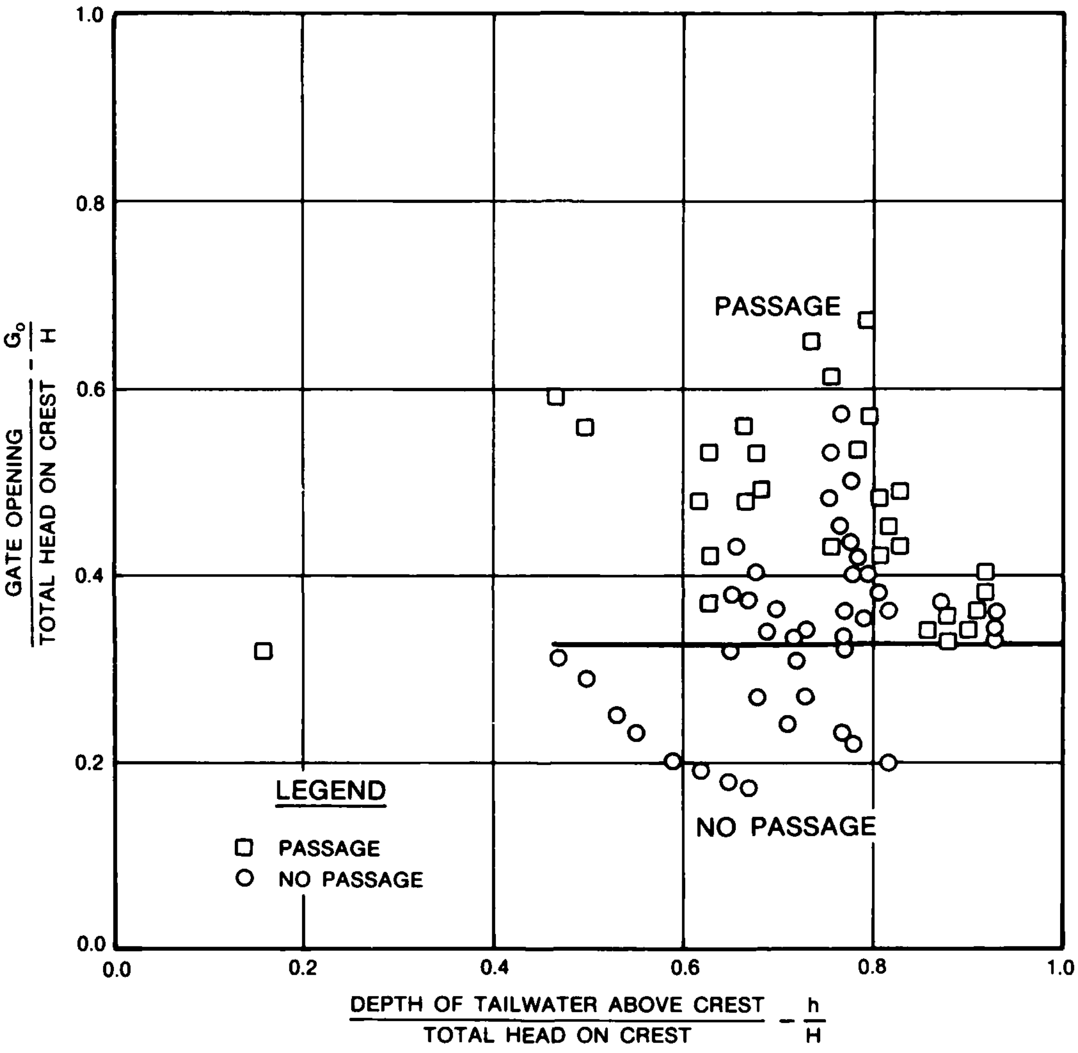
STILLING BASIN UPLIFT TESTS
DISTANCE FROM PIN TO RESULTANT FORCE, LOW BAYS



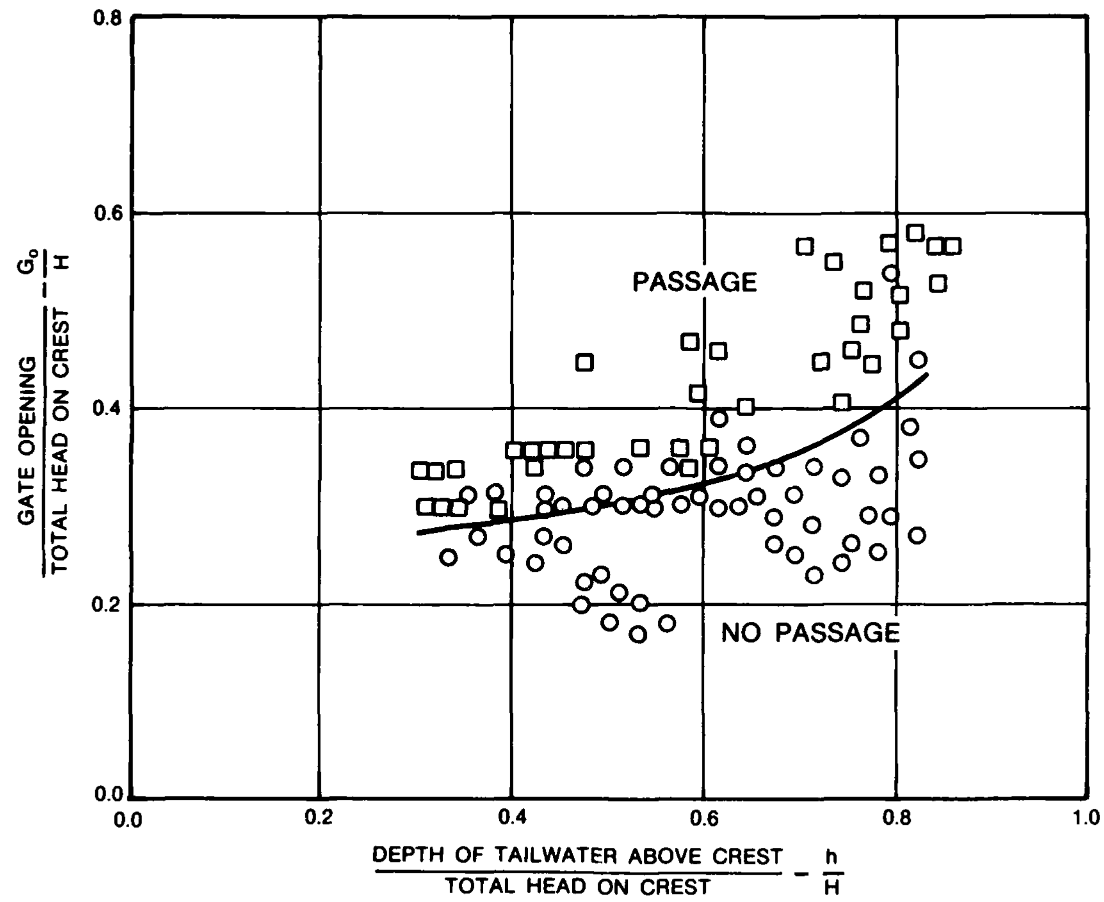
SURVEY BOAT SAFETY
HIGH BAYS



SURVEY BOAT SAFETY
LOW BAYS



DEBRIS PASSAGE
HIGH BAYS



DEBRIS PASSAGE
LOW BAYS

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